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Year: 2015

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DOI: <https://doi.org/10.1257/mac.20130302>

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ZORA URL: <https://doi.org/10.5167/uzh-99431>

Journal Article

Accepted Version

Originally published at:

Acemoglu, Daron; Gancia, Gino; Zilibotti, Fabrizio (2015). Offshoring and directed technical change. *American Economic Journal: Macroeconomics*, 7(3):84-122.

DOI: <https://doi.org/10.1257/mac.20130302>

# Offshoring and Directed Technical Change

By DARON ACEMOGLU, GINO GANCIA, AND FABRIZIO ZILIBOTTI\*

*We study the implications of offshoring on innovation, technology adoption, and wage inequality in a Ricardian model with directed technical change. In our model, profit maximization determines both the extent of offshoring and the direction of technological progress. A fall in the cost of offshoring induces technical change with an ambiguous factor bias. When the initial cost of offshoring is high, an increase in offshoring opportunities causes a fall in the real wages of unskilled workers in the industrialized world, skill-biased technical change and rising skill premia worldwide. When the offshoring cost is sufficiently low, instead, further increases in offshoring opportunities induce technical change biased in favor of the unskilled workers.*

*(JEL: F43, O31, O33)*

The rapid rise of offshoring, which involves many production and service tasks that were previously produced domestically now being sourced from abroad, has been a salient trend in the US labor market over the last three decades. The share of imported inputs in total intermediate use in US manufacturing, for example, has increased from about 6% in 1980 to over 27% today (Feenstra and Jensen 2012), and intermediate inputs account for two thirds of world trade. Offshoring does not only create efficiency gains by enabling the transfer of production to countries with lower labor costs. It also has distributional effects that can have negative consequences on the wages of less skilled workers in advanced economies.<sup>1</sup>

This paper shows that the effect of a reduction in offshoring costs on wages in the industrialized world hinges on the impact of offshoring on the direction of technical change. Though there is a vibrant debate on the exact contribution of skill-biased technical change to wage inequality in industrialized economies, the broad consensus is that the more rapid rise in the demand for skills than the sup-

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<sup>1</sup>See, for example, Feenstra and Hanson (1996), and Deardorff (2001 and 2005). In addition, as pointed out by Samuelson (2004) offshoring could lower income in industrialized nations in a Ricardian trade model if it transferred knowledge to less advanced, lower-wage emerging economies, thus eroding the technological advantage of the former in a range of tasks. Counteracting this are the efficiency gains due to offshoring, emphasized by several authors including Grossman and Rossi-Hansberg (2008) and Rodriguez-Clare (2010), which potentially benefit all workers.

ply has been at the root of much of it and that more skill-biased technologies, at given factor supplies, tend to increase wage inequality (e.g., Autor et al. 2003 and 2008; Acemoglu and Autor 2011). It is also evident that offshoring opportunities should affect the skill bias of technology. Our analysis shows that the induced impact of offshoring on technology first amplifies its negative distributional consequences, but then as the extent of offshoring expands further, its induced effect on technology changes sign and becomes an equalizing force. Thus, the overall impact on wage inequality of an increase in offshoring opportunities is inverse U-shaped.

In our model, a unique final good is produced by combining a skilled and an unskilled product, each produced from a continuum of intermediates (tasks). Offshoring takes the form of some of these intermediates being transferred from an industrialized (henceforth, the *West*) to an emerging (henceforth, the *East*) economy, and is potentially efficiency enhancing because it reallocates production towards countries where wages are lower. In our model, offshoring is subject to both fixed and variable costs, and thus can increase both at the *extensive margin* (more intermediates being offshored) and at the *intensive margin* (lower costs for intermediates already being offshored).

Our main results concern the effects of offshoring on equilibrium technologies. An expansion of offshoring opportunities—either at the extensive or the intensive margin—encourages skill-biased technical change (henceforth, SBTC) by increasing the relative price of high-skill products. Simultaneously, offshoring encourages unskilled labor-biased technical change (henceforth, UBTC) because it expands the market size of technologies complementary to unskilled workers, which can now be used in the East. In the empirically more relevant case where the elasticity of substitution between intermediates (tasks) is greater than the elasticity of substitution between skills and the extent of offshoring is limited initially, the price effect dominates and greater offshoring opportunities induce SBTC.<sup>2</sup> However, when the level of offshoring is already high, the opposite pattern obtains and an increase in offshoring opportunities induces UBTC, thus generating the inverse U-shaped pattern mentioned above. This result hinges on the Ricardian features of our model: first, the efficiency gains are strongest when offshoring is limited, which implies a large wage gap between the West and the East. An expansion in offshoring opportunities increases the demand for labor in the East and closes this gap, reducing the efficiency gains from offshoring in the process. Second, by closing the wage gap between industrialized and emerging economies, offshoring mutes the price effect on the direction of technical change.

As an illustration of the different effects of offshoring, consider the example of Apple products, such as the iPod, for which the overwhelming majority of assembly and production jobs are offshored to the East (Linden et al. 2011).

<sup>2</sup>Here it is important to interpret offshoring broadly as taking place both in production tasks and intermediates produced by unskilled workers, particularly because, as we discuss in Section 2, most of the estimates on the relevant elasticity of substitution come from trade data on intermediates.

Without offshoring opportunities, it may not have been profitable for Apple to introduce some of the new varieties of iPods because of the higher labor costs it would have faced. This would have likely reduced the demand for high-skill engineering and design jobs at Apple, corresponding to the “price effect” which creates a positive link between offshoring and SBTC. Counteracting this, absent the offshoring opportunities, Apple may have designed iPods differently in order to reduce its dependence on expensive domestic unskilled labor, implying a lower demand for unskilled workers in the United States. This second channel illustrates a potential negative link between offshoring and SBTC due to the “market size effect”.<sup>3</sup>

Although our model abstracts from important determinants of wage inequality in the United States (including changes in the domestic supply of skills), it is consistent with the qualitative picture emerging from several decades of changes in the US wage structure. The first wave of offshoring in the 1980s coincides with a sharp decline in the real wages of unskilled workers, but as offshoring continues to expand in the late 1990s and 2000s, unskilled wages stabilize and begin rising (e.g., Acemoglu and Autor 2011). Consistent with these facts, the impact of offshoring on wage inequality is strongest in our model when the volume of trade in intermediates is limited, as in the 1980s. As such, our results circumvent the criticism to trade-based explanations of growing wage inequality that the volume of trade between the United States and developing countries was then too small to have a significant impact on wages.<sup>4</sup>

Our analysis of the transitional dynamics of technology and wages further shows that the two activities are substitutes in the short run, but complements in the long run. Following an expansion in offshoring opportunities, technical change stops for a while because firms first spend resources to offshore the production of existing intermediates. This is followed by a phase of either SBTC (for high offshoring costs) or UBTC (for low offshoring costs). The distributional effects of this transition can in principle harm workers in the West (especially unskilled workers). Our welfare analysis shows that if the post-offshoring growth rate is sufficiently high, all workers benefit from offshoring, but otherwise both skilled and unskilled workers in the West world can lose out. Our quantitative results suggest that while workers in the East gain unambiguously, in the West unskilled workers are most likely to suffer as a result of offshoring, and skilled workers typically obtain limited gains. Yet, all workers may gain if offshoring costs become sufficiently low to trigger UBTC.

In extensions, we further show that when skilled intermediates can also be offshored to the East, an increase in offshoring opportunities tends to increase

<sup>3</sup>See Acemoglu (2002) on the price and market size effects on the direction of technical change.

<sup>4</sup>Our model is also broadly consistent both with Bloom et al. (2011), who find that the surge of imports from China from the late 1990s encouraged investments in information technology across European industries, and with Autor et al. (2013), who show that it also reduced the demand for labor in US local economies heavily exposed to this import competition.

wage inequality in all countries.<sup>5</sup> Moreover, in the presence of a low-productivity imitation technology, the theory predicts that the rise in offshoring opportunities in emerging economies gives rise to only to limited wage growth in the East, consistent with the evidence that the rapid GDP growth in China has not been matched by an equal increase in local wages (especially among low-skill workers).

Our paper is related to a growing literature on offshoring. Even though our main results hinge on the endogenous reaction of technical change, our model of offshoring with fixed technology has implications for the skill premium that are related to, but different from, those emphasized in the literature. In particular, offshoring tends to increase the skill premium through a labor supply effect and a relative price effect, and tends to reduce it through the efficiency effect. This efficiency effect is based on the complementarity between Western and Eastern workers and is similar to the efficiency effect in Rodriguez-Clare (2010). It is also related to Grossman and Rossi-Hansberg's (2008) productivity effect, but with the crucial difference that it is more pronounced when there is little offshoring (and thus a large wage gap between the West and the East) and it vanishes as offshoring increases.<sup>6</sup> Our main point of departure from the offshoring literature is the introduction of directed technical change.<sup>7</sup>

Our paper also builds on models of directed technical change (e.g., Acemoglu 1998, 2002 and 2007; Kiley 1999; Acemoglu and Zilibotti 2001; Gancia and Zilibotti 2009), and especially those linking international trade to the direction of innovation, including Acemoglu (2003), Thoenig and Verdier (2003), Epifani and Gancia (2008), and Gancia, Müller and Zilibotti (2011). All of these papers show how international trade can induce technological changes that further increase the demand for skills, thus amplifying its direct impact on the wage structure. This literature has not, to the best of our knowledge, considered offshoring, which has different effects on incentives for technical change. These effects include the impact of offshoring on the direction of technical change that is independent of international intellectual property rights enforcement;<sup>8</sup> and the non-monotonic

<sup>5</sup>This happens because, despite the presence of complete specialization and technological differences across countries, the zero-profit condition for innovation implies conditional factor price equalization: if offshoring costs are identical, profit maximization implies that the skill premium must be the same in the West and in the East. See Sheng and Yang (2012) for supporting evidence, indicating that processing (offshoring-related) exports and FDI explain a large fraction of the recent increase in the Chinese college wage premium. See also Feenstra and Hanson (1996) for a different mechanism via which offshoring can increase skill premia in all countries.

<sup>6</sup>The nature of this efficiency effect is independent of whether the expansion of offshoring opportunities are at the intensive margin (as in Grossman and Rossi-Hansberg) or at the extensive margin (as in Baldwin and Robert-Nicoud 2014).

<sup>7</sup>Recent contributions studying the effect of offshoring on wages include Antràs et al. (2006), Burstein and Vogel (2012), Costinot et al. (2013), Egger et al. (2013), and Goel (2013). Other studies endogenize the rate, but not the direction, of technical change in the economy in the presence of offshoring (see Glass and Saggi 2001; Naghavi and Ottaviano 2009; Dinopoulos and Segerstrom 2010; Rodriguez-Clare 2010; Branstetter and Saggi 2011; Jakobsson and Segerstrom 2012).

<sup>8</sup>In Acemoglu (2003), trade induces skill-biased technical change when intellectual property rights (IPR) are not enforced internationally, but induces unskilled-labor biased technical change when they are fully enforced. Here because offshoring is voluntary, and thus profitable, its qualitative impact on the direction of technical change is independent of international IPR enforcement. Chu et al. (2014)

relationship between offshoring and the direction of technical change, which crucially depends on the endogeneity of the gap between wages in the West and the East, and thus the extent of the price effect, features related to the Ricardian nature of offshoring.

The rest of the paper is organized as follows. Section I presents our basic model of intermediate/task trade and directed technical change and characterizes the effects of offshoring on wages and skill premia for a given level of technology. Section II contains our main results on the impact of offshoring on the direction of technical change, wages and welfare of different workers. Section III extends the model to include offshoring of high-skill intermediates and technological imitation. Section IV concludes. The Appendix contains the proofs of all propositions and some technical analysis omitted in the text.

## I. Model

In this section, we present our baseline environment and characterize the impact of offshoring on wages holding technology constant and treating offshoring as exogenous. Both technology and the level of offshoring will be endogenized in the next section.

### A. Environment

The world economy comprises two countries, West and East, populated by two types of workers, skilled and unskilled, in fixed supply.<sup>9</sup> The West is endowed with  $L_w$  units of unskilled workers and  $H_w$  units of skilled workers. The East is assumed to be skill scarce. In the benchmark model, we assume that the East has  $L_e$  unskilled workers and no skilled workers. We do so to focus on the simplest (and empirically more relevant) case in which offshoring affects low-skill jobs, but we relax this assumption in Section III. The two countries also differ in their technological capabilities: new technologies (intermediates) are introduced in the West and can be transferred to the East only after paying a fixed offshoring cost. As in earlier models of directed technical change (see, e.g., Acemoglu and Zilibotti 2001; Acemoglu 2002), some technologies complement skilled workers while others complement unskilled workers and the evolution of both is endogenous. There are no barriers to trade of goods across countries, but labor is immobile. Trade is driven both by differences in relative factor endowments, as in the Heckscher-Ohlin model, and by differences in technological capabilities, as in Ricardian models.

Infinitely-lived households derive utility from the consumption of a unique final good, and supply labor inelastically. Preferences are identical across countries

study the effect of changes in the supply of labor in China on the direction of innovation in a model with offshoring. Their results are similar to those obtained in models with directed technical change under international IPR protection.

<sup>9</sup>We use the terms high-skill and skilled, and low-skill and unskilled, interchangeably.

and workers. Consequently, the world economy admits a representative household with preferences at time  $t = 0$  given by

$$U_0 = \int_0^\infty e^{-\rho t} \ln C_t dt,$$

where  $\rho > 0$  is the discount rate. Logarithmic utility is assumed for simplicity, and time indexes will be omitted as long as this causes no confusion.

The final good,  $Y$ , is used for both consumption and investment, and is produced by combining a low-skill and a high-skill good,  $Y_l$  and  $Y_h$ , with a constant elasticity of substitution (CES):<sup>10</sup>

$$(1) \quad Y = \left( Y_l^{\frac{\epsilon-1}{\epsilon}} + Y_h^{\frac{\epsilon-1}{\epsilon}} \right)^{\frac{\epsilon}{\epsilon-1}},$$

where  $\epsilon > 0$  is the elasticity of substitution between  $Y_l$  and  $Y_h$ . We choose the price of the final good,  $Y$ , as the numeraire and define as  $P_l$  and  $P_h$  the world prices of  $Y_l$  and  $Y_h$ , respectively.

The low-skill and high-skill goods are produced from low-skill and high-skill intermediates, also with a CES technology:

$$(2) \quad Y_l = E_l \left( \int_0^{A_l} x_{l,i}^\alpha di \right)^{1/\alpha} \quad \text{and} \quad Y_h = E_h \left( \int_0^{A_h} x_{h,i}^\alpha di \right)^{1/\alpha},$$

where  $x_{l,i}$  is the quantity of low-skill intermediate  $i \in [0, A_l]$ ,  $x_{h,i}$  is the quantity of high-skill intermediate  $i \in [0, A_h]$ , and  $\sigma \equiv 1/(1 - \alpha) > 1$  is the elasticity of substitution. As in models of horizontal innovation (e.g., Romer 1990; see Gancia and Zilibotti 2005 for a survey), the measures of intermediates,  $A_l$  and  $A_h$ , represent the state of technology in the two sectors which grows endogenously over time. The terms

$$(3) \quad E_l \equiv (A_l)^{\frac{2\alpha-1}{\alpha}} \quad \text{and} \quad E_h \equiv (A_h)^{\frac{2\alpha-1}{\alpha}}$$

are technological spillovers introduced to guarantee that the model has balanced growth properties for any  $\sigma$ .<sup>11</sup> We denote  $p_{l,i}$  ( $p_{h,i}$ ) the price of the intermediate variety  $i$ , where  $i \in [0, A_l]$  ( $i \in [0, A_h]$ ).

Each intermediate variety is produced by a single monopolist, either in the West or in the East, using labor. Introducing a new intermediate (either a high-skill or a low-skill variety) requires a sunk innovation cost of  $\mu$  units of the numeraire. Upon

<sup>10</sup>We suppress the distribution parameter of the CES to simplify notation.

<sup>11</sup>Alternative formulations without such spillovers yield identical results, but complicate the algebra, motivating our choice here. See Gancia and Zilibotti (2009) and Acemoglu, Gancia and Zilibotti (2012) for a more detailed discussion of this formulation.

paying  $\mu$ , the innovator is granted the exclusive right to produce the intermediate in the West. In addition, by paying an additional one-time setup cost of  $f$  units of the numeraire, an intermediate firm can offshore production to a partner firm in the East.<sup>12</sup> We denote by  $\kappa$  the fraction of unskilled intermediates offshored to the East, which corresponds to the *extensive margin* of offshoring.

A firm producing one unit of  $x_{h,i}$  requires  $1/Z$  ( $\leq 1$ ) skilled workers. A firm producing one unit of  $x_{l,i}$  in the West requires one unskilled worker. A firm producing one unit of  $x_{l,i}$  in the East requires  $\tau \geq 1$  unskilled worker. The parameter  $\tau$  captures the higher unit-labor requirement of offshoring due to, for instance, coordination and communication costs (e.g., Grossman and Rossi-Hansberg 2008 and 2012).<sup>13</sup> Holding constant  $\kappa$ , declines in  $\tau$  will expand offshoring at the *intensive margin*.

We maintain throughout the paper that  $\kappa < \bar{\kappa} \equiv L_e/(L_e + \tau L_w) < 1$ . This guarantees that equilibrium wages are lower in the East than in the West, and also ensures that intermediates that are offshored will not be produced in the West. Consequently, in equilibrium, a measure  $\kappa A_l$  of unskilled intermediates will be produced in the East and the remaining  $(1 - \kappa) A_l$  in the West. In what follows, we are mostly interested in studying the effect of changes in the costs of offshoring, parametrized by  $f$  and  $\tau$ , especially through their impact on the skill-bias of technology,  $A_h/A_l$ . However, as a preliminary step to understand the determinants of production and wages, we solve the model for given  $A_l$ ,  $A_h$ , and  $\kappa$ .

#### B. Production and Wages with Exogenous Technology and Offshoring

In this subsection, we characterize the equilibrium for a given state of technology,  $A_l$  and  $A_h$ , and for a given level of offshoring,  $\kappa$ . This sets the stage for the dynamic model of section II in which  $A_l$ ,  $A_h$ , and  $\kappa$  will be endogenized. We show that, if technology is held constant, for plausible parameter values an exogenous expansion in offshoring ( $\kappa$ ) increases the skill premium, increases the real wage of skilled workers in the West, and that of unskilled workers in the East, whereas it can reduce the real wage of unskilled workers in the West.

The quantity produced of any intermediate variety in the West and the East can be obtained by imposing labor market clearing as

$$(4) \quad x_h = \frac{ZH_w}{A_h}, \quad x_{l,w} = \frac{L_w}{(1 - \kappa) A_l} \quad \text{and} \quad x_{l,e} = \frac{L_e}{\tau \kappa A_l}.$$

<sup>12</sup>In the working paper version, we also allowed for contractual frictions, such as imperfect IPR protection, lowering the profit share appropriated by offshored firms (e.g., Antras, 2005). The effect of changes in these contractual frictions is similar to changes in  $f$  and is omitted to save space.

<sup>13</sup>The main insights of our analysis can be captured by setting  $\tau = 1$ . However, allowing  $\tau > 1$  is useful both for comparison with Grossman and Rossi-Hansberg (2008) and for additional comparative static results.



Next, we can solve for the East-West unskilled wage gap:

$$(5) \quad \frac{w_{l,w}}{w_{l,e}} = \tau \frac{p_{l,w}}{p_{l,e}} = \tau \left( \frac{x_{l,e}}{x_{l,w}} \right)^{1-\alpha} = \tau \left( \frac{L_e}{L_w} \frac{1-\kappa}{\tau\kappa} \right)^{1-\alpha},$$

where the first equality follows from constant markups, the second from the demand for  $x_{l,e}$  and  $x_{l,w}$  derived from (2) and the third uses (4). From (5), it is easy to verify that  $\kappa < \bar{\kappa}$  implies that  $w_{l,w} > \tau w_{l,e}$ : i.e., the cost of production is lower in the East. If more firms relocate production to the East (i.e.,  $\kappa$  goes up), the demand for unskilled workers falls in the West and increases in the East, thereby compressing the wage gap. At  $\kappa = \bar{\kappa}$ , there is “conditional factor price equalization”: the lower wage in the East just offsets the lower productivity of labor ( $w_{l,w} = \tau w_{l,e}$ ). Note also that, holding  $\kappa$  constant, the elasticity of substitution between unskilled workers in the West and East is  $\sigma \equiv 1/(1-\alpha)$ .

Substituting (4) into (2), and using (3), the world production of the low-skill good can be expressed as:

$$(6) \quad Y_l = A_l \hat{L},$$

where

$$(7) \quad \hat{L} \equiv \left( \kappa^{1-\alpha} (L_e/\tau)^\alpha + (1-\kappa)^{1-\alpha} L_w^\alpha \right)^{1/\alpha}$$

is a weighted average of the East’s and the West’s endowments of unskilled workers, with weights depending on the level of offshoring,  $\kappa$ . As in standard models of horizontal innovation, equation (6) shows that production increases linearly in the number of existing varieties,  $A_l$ . More interestingly, for a given number of varieties, equation (7) shows that production increases in the extent of offshoring:

$$\frac{\partial \hat{L}}{\partial \kappa} = \frac{1-\alpha}{\alpha} \hat{L}^{1-\alpha} \left[ \left( \frac{L_e}{\tau\kappa} \right)^\alpha - \left( \frac{L_w}{1-\kappa} \right)^\alpha \right] > 0,$$

with  $\lim_{\kappa \rightarrow 0} \partial \hat{L} / \partial \kappa = \infty$  and  $\lim_{\kappa \rightarrow \bar{\kappa}} \partial \hat{L} / \partial \kappa = 0$ . We refer to this as the *efficiency effect* of offshoring: an increase in  $\kappa$  induces an efficiency-enhancing reallocation of production towards countries where wages are lower.<sup>14</sup> In terms of equation (6), the increase in  $\kappa$  is equivalent to an increase in the world factor endowment—rising from  $\hat{L} = L_w$  (when  $\kappa \rightarrow 0$ ) to  $\hat{L} = L_w + L_e/\tau$  (when  $\kappa \rightarrow \bar{\kappa}$ ). Importantly, the efficiency effect is stronger when wages in the East are lower, i.e., when there is

<sup>14</sup>This effect is similar to the efficiency effect emphasized in Rodriguez-Clare (2010), from which we take the name. There is also a similarity with models of imperfect international factor mobility (e.g., Gourinchas and Jeanne 2006). Here, the imperfectly mobile factor is knowledge, and offshoring is a form of technology transfer, but naturally differences in knowledge imply differences in technologies across countries as in Ricardian models of trade.

little offshoring (low  $\kappa$ ); when the East has a large relative endowment of unskilled workers (high  $L_e/L_w$ ); and the unit cost of offshoring,  $\tau$ , is low. This is intuitive in view of the fact that the efficiency effect exploits the wage gap between East and West, which is inversely related to  $\kappa$  and  $L_w/L_e$ , and that higher  $\tau$  reduces the possible gains from offshoring. A fall in the unit cost of offshoring,  $\tau$ , also increases production of the low-skill good. In this case, the magnitude of the effect is proportional to the extent of offshoring,  $\kappa$ .<sup>15</sup>

We now study the determinants of wages in the West. We consider, first, the effect of changes in  $\kappa$  and  $\tau$  on the skill premium, and then on wage levels. Denote the skill premium in the West by  $\omega_w \equiv w_{h,w}/w_{l,w}$ . Constant markups imply that  $\omega_w = Z(p_{h,w}/p_{l,w})$ . As shown in the Appendix, the skill premium can be expressed as:

$$\begin{aligned}
 \omega_w &= Z \left( \frac{E_h}{E_l} \right)^\alpha \frac{P_h}{P_l} \left( \frac{Y_h}{Y_l} \frac{x_{l,w}}{x_{h,w}} \right)^{1-\alpha} \\
 (8) \quad &= \left( \frac{Z A_h}{A_l} \right)^{1-1/\epsilon} \left( \frac{L_w}{1-\kappa} \right)^{1-\alpha} \left( \frac{H_w}{\hat{L}} \right)^{-1/\epsilon} \frac{1}{\hat{L}^{1-\alpha}},
 \end{aligned}$$

where, recall,  $\hat{L}$  is increasing in  $\kappa$  and decreasing in  $\tau$ . The first equation shows that the skill premium is increasing in the relative price ( $P_h/P_l$ ) and the relative aggregate demand ( $Y_h/Y_l$ ) for high-skill products, and decreasing in relative firm size ( $x_{h,w}/x_{l,w}$ ). The second line shows that the impact of an increase in  $\kappa$  (corresponding to an expansion of offshoring at the extensive margin) on the skill premium can be decomposed into a *labor supply* effect,  $(L_w/(1-\kappa))^{1-\alpha}$ , a *relative price* effect,  $(H_w/\hat{L})^{-1/\epsilon}$ , and an *efficiency* effect,  $\hat{L}^{\alpha-1}$ . The first two effects increase the skill premium, whereas the third one reduces it.

We now discuss each of these three effects in detail. First, offshoring displaces Western unskilled workers who must be rehired by the remaining domestic firms. Holding prices ( $P_h/P_l$ ) constant, this is analogous to an increase in the supply of unskilled workers in the West, which in turn increases the skill premium. Second, offshoring increases low-skill production, raising the relative price of the high-skill goods. This relative price effect also increases the skill premium. Third, offshoring raises the overall efficiency of low-skill production, expanding the relative demand for unskilled workers also in the West. The effect is stronger when the complementarity between unskilled workers in the West and the East is greater (low  $\alpha$ ) and when the initial level of offshoring ( $\kappa$ ) is lower.

An inspection of (8) shows that the efficiency effect is dominated by the price effect whenever  $\sigma > \epsilon$  (i.e.,  $1 - \alpha < 1/\epsilon$ ). That is, if the elasticity of substitution between intermediates produced in the East and in the West (or between unskilled workers in the East and in the West) is greater than the elasticity of substitution between high- and low-skill goods, then offshoring necessarily increases the skill

<sup>15</sup>This effect is similar to the productivity effect in Grossman and Rossi-Hansberg (2008).

premium in the West. In the opposite case ( $\sigma < \epsilon$  or  $1 - \alpha > 1/\epsilon$ ), the efficiency effect dominates the price effect. Whether it also dominates the labor-supply effect depends on the level of offshoring. Since  $\lim_{\kappa \rightarrow 0} \partial \hat{L} / \partial \kappa = \infty$ , for low levels of  $\kappa$ , the efficiency effect is so strong that offshoring raises the relative reward to the offshored factor. For high levels of offshoring, however, only the labor-supply effect remains (recall that  $\lim_{\kappa \rightarrow \bar{\kappa}} \partial \hat{L} / \partial \kappa = 0$ ). The relationship between  $\omega_w$  and  $\kappa$  in the two cases is depicted in Figure 1.

FIGURE 1 HERE

Consider, next, the intensive margin of offshoring (a fall in  $\tau$ ). By raising  $\hat{L}$ , a lower  $\tau$  increases the skill premium in the West if  $\sigma > \epsilon$ . The impact of a fall in  $\tau$  on the skill premium is opposite if  $\sigma < \epsilon$ .<sup>16</sup>

Since a number of effects of offshoring vary depending on whether  $\sigma$  is larger or smaller than  $\epsilon$ , it is useful to identify the empirically plausible scenario. With no offshoring ( $\kappa = 0$ ), the parameter  $\epsilon$  corresponds to the aggregate short-run elasticity of substitution between skilled and unskilled workers in the West holding constant technology. In a world with positive offshoring ( $\kappa > 0$ ),  $\epsilon$  is still the aggregate short-run elasticity holding constant  $\kappa$  and  $L_e/\tau L_w$ .<sup>17</sup> Available estimates of this parameter are in the range  $[1.5, 2]$  (see Ciccone and Peri 2005, and references therein). Ciccone and Peri (2005) also reports estimates for the United States over the period 1950-70, when offshoring was negligible, and find a value of 1.61. The parameter  $\sigma$  corresponds to the elasticity of substitution between traded intermediates in the low-skill sector, which is difficult to observe directly. Yet, given that two thirds of the volume of trade is in intermediate inputs, we can gauge the magnitude of this parameter from estimates of substitutability across traded varieties. The vast majority of these estimates are above 3 (see Hillberry and Hummels 2012 for a survey) and tend to be higher in low-skill sectors (e.g., Broda and Weinstein 2006). This implies that  $\sigma > \epsilon > 1$  is the empirically more plausible case, although the opposite may well hold true in some specific industries. In addition, recalling that  $\sigma$  also corresponds to the short-run (constant  $\kappa$ ) elasticity of substitution between unskilled workers in the West and East, letting  $\sigma > \epsilon$  amounts to assuming that unskilled workers in the West and in the East are closer substitute than are skilled and unskilled workers. This seems a plausible assumption. With this motivation, in the rest of the paper we focus on the case

<sup>16</sup>This result generalizes the “productivity effect” of Grossman and Rossi-Hansberg (2008) by showing how the strength of this mechanism depends on the elasticity of substitution between offshored and non-offshored intermediates (Grossman and Rossi-Hansberg 2008 assumes no substitutability).

<sup>17</sup>To see this, note that, combining (7) and (8),  $\omega_w$  is proportional to

$$\left(\frac{H_w}{L_w}\right)^{-1/\epsilon} \left[ \left( \kappa^{1-\alpha} \left( \frac{L_e}{\tau L_w} \right)^\alpha + (1-\kappa)^{1-\alpha} \right)^{1/\alpha} \right]^{\alpha+1/\epsilon-1}.$$

in which  $\sigma > \epsilon > 1$ . The analysis of the complementary case is presented in the Appendix.

We now study the effect of offshoring on wage *levels*. It is easy to establish that wages of both high-skill and Eastern workers increase unambiguously with offshoring (see Proposition 1). The effect on the wage of low-skill workers in the West is more complex. As shown in the Appendix, the low-skill wage in the West is given by:

$$(9) \quad w_{l,w} = \alpha P_l A_l \hat{L}^{1-\alpha} \left( \frac{1-\kappa}{L_w} \right)^{1-\alpha},$$

where  $P_l = (Y/Y_l)^{1/\epsilon}$ . The impact of  $\kappa$  and  $\tau$  on  $w_{l,w}$  can again be decomposed into a *price effect*, an *efficiency effect* and a *labor supply effect*. The interpretation is related to the discussion above concerning the skill premium: offshoring decreases the unskilled wage via both the price and labor supply effects, whereas it increases  $w_{l,w}$  via the efficiency effect.

Consider, first, the effect of an increase in  $\kappa$ . When the initial level of offshoring is high (i.e., as  $\kappa \rightarrow \bar{\kappa}$ ), both the price and the efficiency effects vanish, and offshoring reduces unskilled wages unambiguously. However, the effect of offshoring is ambiguous for low initial level of  $\kappa$ . We show in the Appendix that an increase in  $\kappa$  necessarily lowers  $w_{l,w}$  when (i)  $\sigma > \epsilon$  and (ii)

$$(10) \quad \frac{A_h Z H_w}{A_l \hat{L}} > \left( \frac{\epsilon}{\sigma - \epsilon} \right)^{\frac{\epsilon}{\epsilon-1}}.$$

The relationship between  $\kappa$  and the three wage levels is depicted in Figure 2 for this case. Note that when either  $\sigma < \epsilon$  or condition (10) is reversed, the relationship between offshoring and unskilled wage in the West is inverse U-shaped.

FIGURE 2 HERE

The effect of a change in  $\tau$  is similar. A fall in the unit cost of offshoring increases  $\hat{L}$  with ambiguous effects on  $w_{l,w}$ . In the Appendix (see proof of Proposition 1), we also establish that a fall in  $\tau$  lowers  $w_{l,w}$  as long as condition (10) is satisfied. When either  $\sigma < \epsilon$  or condition (10) is reversed, then a fall in the unit cost of offshoring increases unskilled wages.

The following proposition summarizes the effects on wages of an exogenous increase in offshoring when technology is held constant.

**PROPOSITION 1:** *Suppose  $\sigma > \epsilon > 1$ . With exogenous technology and offshoring, an increase in offshoring, parameterized by an increase in  $\kappa$ :*

(i) *increases the skill premium,  $\omega_w$ ;*

- (ii) increases the real wage of skilled workers in the West,  $w_{h,w}$ , and the real wage of unskilled workers in the East,  $w_{l,e}$ ;
- (iii) decreases the real wage of unskilled workers in the West,  $w_{l,w}$ , if (10) is satisfied. If (10) is not satisfied, the effect of  $\kappa$  on  $w_{l,w}$  is inverse U-shaped: it increases  $w_{l,w}$  for low initial values of  $\kappa$ , and decreases  $w_{l,w}$  for high initial values of  $\kappa$ .

## II. Equilibrium with Endogenous Offshoring and Technology

In this section, we endogenize offshoring ( $\kappa$ ) and technology ( $A_h$  and  $A_l$ ) in the dynamic world equilibrium. We characterize the effect of a reduction in the cost of offshoring on the extent of offshoring, the skill bias of technology and the skill premium in the West (Proposition 3). Our main result is the inverse U-shaped relationship between the equilibrium skill bias of technology and an inverse measure of barriers to offshoring (Proposition 4). In particular, when offshoring costs are initially large, a reduction in these costs induces SBTC and increases the skill premium in the West. On the contrary, when offshoring costs are initially already low, further reduction in such costs induces UBTC and (under some parameter conditions) decreases the skill premium. In later subsections, we also study the transitional dynamics of equilibria and present a brief quantitative analysis to gauge the different welfare effects of lower costs of offshoring.

Recall that new intermediates are initially produced in the West, but by paying an additional set-up cost,  $f$ , Western firms have the option to offshore the production of low-skill intermediates to a partner firm in the East. In addition, firms in the West can also innovate to generate new varieties by paying a fixed cost  $\mu$ . The benefits of innovation and offshoring are the profit streams from selling an intermediate. Let  $V_h$  be the value of a high-skill firm (i.e., a firm selling a high-skill variety). The asset price equation must satisfy the usual Hamilton-Jacobi-Bellman (HJB) equation:

$$(11) \quad rV_h = \pi_h + \dot{V}_h.$$

Consider, next, firms producing low-skill intermediates. We denote by  $V_l^o$  the value of a firm that has already paid the offshoring cost, and by  $V_l$  the value of a firm producing a low-skill intermediate in the West. These value functions are determined by the following HJB equations:

$$(12) \quad \begin{aligned} rV_l^o &= \max\{\pi_{l,w}, \pi_{l,e}\} + \dot{V}_l^o, \\ rV_l &= \max\{\pi_{l,w} + \dot{V}_l, r(V_l^o - f)\}. \end{aligned}$$

The max operator in the first HJB equation captures the fact that the firm will produce in the most profitable location. In any equilibrium with offshoring, it is more profitable to produce in the East, i.e.,  $\pi_{l,e} > \pi_{l,w}$ . The max operator in the

second HJB equation captures the option for the non-offshoring firm to pay the cost  $f$ , offshore its production, and change its value to  $V_l^o$ .

#### A. Balanced Growth Path

We consider first the balanced growth path equilibrium (BGP). Free-entry implies that the value of introducing a new intermediate and the value of offshoring the production of an existing intermediate cannot exceed their respective costs:  $V_l^o - V_l \leq f$ ,  $V_l \leq \mu$ , and  $V_h \leq \mu$ . In a BGP with positive innovation and offshoring, all free-entry conditions must hold as equalities:

$$(13) \quad V_l = V_h = \mu, \text{ and } V_l^o = f + \mu.$$

This set of free-entry conditions pins down the BGP interest rate:

$$(14) \quad r = \frac{\pi_{l,e} - \pi_{l,w}}{f} = \frac{\pi_{l,w}}{\mu} = \frac{\pi_h}{\mu}.$$

The arbitrage conditions in (14) pin down the offshoring rate ( $\kappa$ ) and the skill bias of technology ( $A_h/A_l$ ). The resulting equilibrium values are summarized in the following proposition.

**PROPOSITION 2:** *Suppose  $\sigma > \epsilon > 1$  and  $\rho\sigma\mu < \min\{L_w, ZH_w\}$ . Let  $\lambda \equiv (f/\mu + 1)^{-1} \in [0, 1]$ . Then, there exists a unique BGP in which the offshoring rate is*

$$(15) \quad \kappa = \left(1 + \lambda^{-1/\alpha} \tau L_w / L_e\right)^{-1};$$

*the relative technologies are*

$$(16) \quad \frac{A_h}{A_l} = (ZH_w)^{\epsilon-1} \hat{L}^{1-\epsilon+\epsilon\alpha} \left(\frac{1-\kappa}{L_w}\right)^{\epsilon\alpha};$$

*and consumption and output grow at the rate*

$$(17) \quad g = \frac{1-\alpha}{\mu} \left\{ \left[ \hat{L}^{1-\alpha} \left( L_w + \lambda^{1/\alpha} L_e \tau^{-1} \right)^\alpha \right]^{\epsilon-1} + (ZH_w)^{\epsilon-1} \right\}^{\frac{1}{\epsilon-1}} - \rho > 0.$$

Consider the equilibrium offshoring rate and note that  $\lambda \equiv (f/\mu + 1)^{-1}$  is an inverse measure of the cost of offshoring production (or, identically, a measure of offshoring opportunities), ranging from  $\lambda = 0$  (prohibitive offshoring costs) to  $\lambda = 1$  (no offshoring cost). From equation (15), an increase in  $\lambda$  or a fall in  $\tau$  makes offshoring more profitable, thereby increasing  $\kappa$ . The effect of a change in either  $\lambda$  or  $\tau$  on the direction of technical change is more complex, as these

parameters affect both  $\kappa$  and  $\hat{L}$  in equation (16). For simplicity, in the rest of this section we focus on the comparative statics of an increase in  $\lambda$  (stemming from a fall in the fixed cost  $f$ ) on the direction of technical change. A reduction in  $\tau$  has similar effects, as discussed in more details in the Appendix.

In general, the relationship between  $A_h/A_l$  and  $\lambda$  is non-monotonic, being increasing for high cost of offshoring (i.e., low initial  $\lambda$ ) and decreasing for high cost of offshoring (i.e., high initial  $\lambda$ ). This is illustrated by Figure 3 which shows the equilibrium relationship between the BGP level of  $A_h/A_l$  and  $\kappa$  for two empirically plausible values of  $\sigma$ , such that  $\sigma > \epsilon$ . Different points on each schedule correspond to different values of  $\lambda$  ranging between zero and unity. In particular,  $\lambda = 0$  implies  $\kappa = 0$ , while  $\lambda = 1$  implies that  $\kappa = \bar{\kappa}$  on the horizontal axis. For future reference, we denote by  $\hat{\lambda}$  the value of  $\lambda$  that maximizes  $A_h/A_l$ .<sup>18</sup>

FIGURE 3 HERE

To understand the intuition behind the inverse U-shaped relationship between  $\lambda$  and the skill bias of technology, it is useful to note that, as in the canonical model of directed technical change (e.g., Acemoglu 2002), the relative value of new innovations hinges on a *price effect* and on a *market size effect*. Recalling that  $V_h/V_l = \pi_{h,w}/\pi_{l,w}$ , and using (4) and (8), we obtain

$$(18) \quad \frac{V_h}{V_l} = \underbrace{\frac{P_h}{P_l}}_{\text{price effect}} \cdot \underbrace{\frac{ZH_w}{\hat{L}^{1-\alpha} \left( \frac{L_w}{1-\kappa} \right)^\alpha}}_{\text{market size effect}} = \underbrace{\left( \frac{A_l \hat{L}}{A_h H_w} \right)^{1/\epsilon}}_{\text{price effect}} \cdot \underbrace{\frac{ZH_w}{\hat{L}^{1-\alpha} \left( \frac{L_w}{1-\kappa} \right)^\alpha}}_{\text{market size effect}}.$$

The price effect is relatively standard. An increase in  $\lambda$  improves the allocation of labor worldwide. The resulting increase in  $\hat{L}$  pushes up the production of the low-skill good,  $Y_l$ , that in turn raises the relative price of the high-skill good and the profitability of high-skill innovation. In contrast, the market size effect is richer than in the canonical model, and comprises two effects. On the one hand, as more tasks and sectors are offshored to the East, each low-skill intermediate still produced in the West employs more workers and is produced in greater quantity. We refer to this effect, captured by the term  $L_w/(1-\kappa)$  in equation in (18), as a *direct market size effect*. Here, the fall in  $\kappa$  induces UBTC. On the other hand, the market size of low-skill technologies also depends, positively, on  $\kappa$  and  $L_e$ , through the term  $\hat{L}^{1-\alpha}$ . We refer to this effect as a *complementary market size effect*. This effect hinges on the extent of the complementarity across intermediates: as  $\alpha \rightarrow 1$  (i.e., the intermediates are perfect substitutes), the

<sup>18</sup>Formally,  $\hat{\lambda} = \phi^{-1}((\epsilon\alpha^2)/((1-\epsilon+\epsilon\alpha)(1-\alpha)))$ , where  $\phi(\lambda) \equiv (\hat{L}(\lambda))^{-\alpha} \left( (\kappa(\lambda))^{-\alpha} (L_e/\tau)^\alpha - (1-\kappa(\lambda))^{-\alpha} L_w^\alpha \right) (1-\kappa(\lambda))$  is monotonically decreasing in  $\lambda$ .

effective market size becomes independent of  $\hat{L}$ . Conversely, when  $\alpha$  is small (i.e., the intermediates are highly complementary) this effect becomes stronger. Note that both the price effect and the complementary market size effect work entirely through  $\hat{L}$ . Under the assumption that  $1/(1-\alpha) \equiv \sigma > \epsilon$ , the price effect always dominates the complementary market size effect, ensuring that an increase in  $\hat{L}$  necessarily enhances the profitability of skill-biased innovations.<sup>19</sup>

The inverse U-shaped pattern of Figure 3 stems from the fact that the price effect (net of the complementary market size effect) is very large when  $\lambda \rightarrow 0$  and  $\kappa \rightarrow 0$ , and dominates the direct market size effect in the low- $\lambda$  region. Thus, an increase in  $\lambda$  yields an increase in offshoring and SBTC. However, the market size effect dominates when  $\lambda$  is larger.<sup>20</sup> Eventually, the price effect vanishes as  $\kappa \rightarrow \bar{\kappa}$ , while the direct market size effect remains. In this region, a reduction in  $\lambda$  leads unambiguously to more offshoring and UBTC. In other words, when  $\kappa$  is small, wages in the East are so low that the effect of more offshoring opportunities is a large fall in the relative price of low-skill goods inducing SBTC. On the contrary, when wages in the East are already high (i.e., high  $\kappa$ ), the price effect is small so that more offshoring opportunities induce UBTC.

It is useful to compare these results with those obtained in models of trade and directed technical progress, such as Acemoglu (1998 and 2003), Acemoglu and Zilibotti (2001) and Gancia, Müller and Zilibotti (2011). In those models, equation (18) simplifies to  $V_h/V_l = (P_h/P_l) \cdot (ZH/L)$ . Moreover, innovation is only carried out in the skill-rich West. When the West starts trading with the East,  $H/L$  falls relative to autarky. If patents are not protected in the South, the market size for new technologies does not change. Then, the only effect will be an increase in the world price of high-skill products ( $P_h/P_l$ ), which induces SBTC. With global patent protection, the market size dominates the price effect and the larger endowment of unskilled workers in the world economy induces UBTC. Our model nests these two extreme scenarios and predicts an endogenous switch from SBTC to UBTC as global economic integration proceeds. The reason is that the relative strength of the price effect varies endogenously with the level of offshoring: it dominates when wages in the East are low and the efficiency effect is strong, but it disappears as more offshoring eliminates the cost differences between the East and the West.

Next, consider the effect of offshoring on innovation and long-run growth. The BGP growth rate (17) can be characterized by combining the Euler equation for

<sup>19</sup>We report the the results for  $\sigma < \epsilon$  in the Appendix.

<sup>20</sup>More formally, the BGP ratio of technologies, (16), is found by imposing the equal profit condition,  $V_l = V_h$ , in equation (18). The effect of  $\lambda$  on the direction of technical change can be expressed as:

$$(19) \quad \frac{\partial \ln(A_h/A_l)}{\partial \lambda} = \left[ (1 - \epsilon + \epsilon\alpha) \frac{\partial \ln \hat{L}}{\partial \kappa} - \frac{\epsilon\alpha}{1 - \kappa} \right] \frac{\partial \kappa}{\partial \lambda}.$$

This derivative is positive for small values of  $\lambda$  (i.e., low  $\kappa$ ), because  $\partial \ln \hat{L} / \partial \kappa \rightarrow \infty$  as  $\kappa \rightarrow 0$ . However, it changes sign and turns negative for higher values of  $\lambda$  (i.e., high  $\kappa$ ), because  $\partial \ln \hat{L} / \partial \kappa \rightarrow 0$  as  $\kappa \rightarrow \bar{\kappa}$ . A similar result can be proven concerning the comparative statics of  $\tau$ .



consumption,  $g = r - \rho$ , with the free-entry condition for innovation,  $r = \pi_h/\mu$ . Since  $\partial \hat{L}/\partial \lambda > 0$  and  $\partial \hat{L}/\partial \tau < 0$ , (17) shows that an increase in offshoring opportunities (i.e., higher  $\lambda$  or lower  $\tau$ ) increases the BGP growth rate by raising overall profitability.

The next proposition summarizes the main effects of global economic integration on technology discussed so far (proof in the text).

**PROPOSITION 3:** *Suppose  $\sigma > \epsilon > 1$  and  $\rho\sigma\mu < \min\{L_w, ZH_w\}$ . In the BGP, greater offshoring opportunities parameterized by an increase in  $\lambda$ :*

- (i) *increase the offshoring rate,  $\kappa$ ;*
- (ii) *induce SBTC (higher  $A_h/A_l$ ) for low initial  $\lambda$ , and UBTC (lower  $A_h/A_l$ ) for high initial  $\lambda$ ;*
- (iii) *increase the equilibrium interest rate,  $r$ , and the growth rate,  $g$ .*

#### B. The Impact of Offshoring on Wages with Endogenous Technology

In this subsection, which contains the main results of the paper, we derive the implications of an increase in offshoring opportunities for the skill premium in the West when technical change is endogenous.

Substituting (16) into (8) yields the BGP skill premium:<sup>21</sup>

$$(20) \quad \omega_w = Z^{\epsilon-1} H_w^{\epsilon-2} \hat{L}^{1-\epsilon+\epsilon\alpha} \left( \frac{L_w}{1-\kappa} \right)^{1-\epsilon\alpha}.$$

The effect of offshoring on the skill premium is generally non-monotonic and depends on  $\epsilon$  and  $\alpha$ .<sup>22</sup> For a range of low  $\lambda$  (inducing low offshoring), the efficiency effect working through an increase in  $\hat{L}$  is the dominant force, and the skill premium increases with  $\lambda$  for two reasons. The first is the static effect presented in the previous section. The second is that globalization induces SBTC. For higher initial  $\lambda$ 's, however, the relationship may switch sign. More precisely, if  $\epsilon > 1/\alpha$ , then there exists a region of high  $\lambda$  such that the skill premium falls as  $\lambda$  increases. In this case, the long-run relationship between  $\omega_w$  and  $\lambda$  is inverse U-shaped. Note that this outcome is more likely when the substitutability

<sup>21</sup>In the polar opposite cases of prohibitive offshoring costs ( $\kappa = 0$ ) and zero offshoring costs ( $\kappa = \bar{\kappa}$ ), the skill premium is a function of the relative endowment of skilled labor in the West and in the entire world, respectively:

$$\omega_w |_{\lambda=0} = Z^{\epsilon-1} \left( \frac{H_w}{L_w} \right)^{\epsilon-2}, \quad \omega_w |_{\lambda=1} = Z^{\epsilon-1} \left( \frac{H_w}{L_w + L_e \tau^{-1}} \right)^{\epsilon-2}.$$

As in standard models of directed technical change (e.g., Acemoglu, 1998, 2002), the relationship between the skill premium and the relative supply of skill is increasing whenever  $\epsilon > 2$ .

<sup>22</sup>This can be seen more formally by differentiating (20) with respect to  $\lambda$ :

$$\frac{\partial \ln \omega_w}{\partial \lambda} = \left[ (1 - \epsilon + \epsilon\alpha) \frac{\partial \ln \hat{L}}{\partial \kappa} + \frac{1 - \epsilon\alpha}{1 - \kappa} \right] \frac{\partial \kappa}{\partial \lambda}.$$

between low-skill intermediates is high. If  $\sigma = 5$ , the inverted U shape holds for  $\epsilon \in (1.25, 5)$ , which includes the range of consensus estimates of the elasticity of substitution between skill groups.

The solid line in Figure 4 shows the relationship between the skill premium and the offshoring rate ( $\kappa$ ) for  $\epsilon = 1.6$  and  $\sigma = 3.33$ . As before, each point on the solid line corresponds to a different  $\lambda$  ranging between zero to one, so that  $\kappa = (1 + \lambda^{-1/\alpha} \tau L_w / L_e)^{-1}$  moves from zero to  $\bar{\kappa}$  on the horizontal axis. For comparison, we also report a dashed line showing how the skill premium would have evolved if the technology had remained constant at the autarky level. As the figure illustrates, the endogenous reaction of technology provides a strong amplification of the impact of offshoring on the skill premium for relatively low levels of integration, while this effect is reverted for high levels of offshoring.<sup>23</sup> Thus, the combination of offshoring with directed technical change can explain a large surge in the skill premium even for low levels of offshoring (and hence trade) between the West and the East. Note also that the non-monotonic relationship is entirely driven by the endogenous response of technology.

FIGURE 4 HERE

The next proposition summarizes the effects of offshoring on wages once the endogenous response of technology is factored in:

**PROPOSITION 4:** *Suppose  $\sigma > \epsilon > 1$  and  $\rho\sigma\mu < \min\{L_w, ZH_w\}$ . In the BGP, greater offshoring opportunities parameterized by an increase in  $\lambda$ :*

- (i) *reduce the wage gap between unskilled workers in the East and in the West,  $w_{l,e}/w_{l,w}$ ;*
- (ii) *raise the skill premium in the West,  $\omega_w$ , if  $\sigma / (\sigma - 1) > \epsilon$ ; if  $\epsilon > \sigma / (\sigma - 1)$ , they increase  $\omega_w$  for a region of low initial  $\lambda$ , and decrease  $\omega_w$  for a region of high initial  $\lambda$ .*

A fall in the unit cost of offshoring ( $\tau$ ) has similar effects as an increase in  $\lambda$ . As shown in the Appendix, for low levels of  $\lambda$  (low  $\kappa$ ) and  $\sigma > \epsilon$ , a fall in  $\tau$  increases  $\omega_w$ . In contrast, starting from high levels of  $\lambda$  (high  $\kappa$ ), a fall in  $\tau$  decreases  $\omega_w$  when  $\epsilon > 2$ . In the Appendix we also state the analogues of Propositions 2, 3 and 4 for the case of  $\sigma < \epsilon$ . The main differences are that, in the low  $\sigma$  case, an increase in offshoring opportunities necessarily induces UBTC, and generates either a U-shaped response or a monotonically decreasing response in the skill premium.

<sup>23</sup>The pattern presented in Figure 3 also suggests that the amplification effect would be even stronger for higher, but still plausible, values of  $\sigma$ .

### C. Transitional Dynamics

The analysis of the previous two subsections has focused on the BGP predictions of the theory. We now turn to the transitional dynamics. We focus on the effects of a (small) unexpected increase in offshoring opportunities parametrized by an increase in  $\lambda$  due to a fall in  $f$ , henceforth, an *offshoring shock*. This shock increases the BGP offshoring rate,  $\kappa$ , and also affects the skill bias of technology according to Proposition 3. The next proposition characterizes the transitional dynamics of  $\kappa$ ,  $A_h$  and  $A_l$ .

**PROPOSITION 5:** *Suppose that  $\sigma > \epsilon > 1$ , the economy is initially in a BGP, and there is a positive offshoring shock (i.e., an increase in  $\lambda$ ) at time  $t = 0$ . Then, the dynamic equilibrium path converges in finite time to a new BGP with a higher offshoring rate. Moreover:*

- (i) *If  $\lambda < \hat{\lambda}$ , then the offshoring shock induces a two-stage transition whereby, for some  $T$  and  $\tilde{T}$  such that  $0 < T < \tilde{T} < \infty$ , we have: (stage 1)  $\dot{\kappa}_t > 0$ ,  $\dot{A}_{l,t} = \dot{A}_{h,t} = 0$  for all  $t \in [0, T]$ ; (stage 2, SBTC)  $\dot{\kappa}_t > 0$ ,  $\dot{A}_{h,t} > 0$ , and  $\dot{A}_{l,t} = 0$  for all  $t \in [T, \tilde{T}]$ . The economy reaches the new BGP at  $t = \tilde{T}$ . In the new BGP, the technology is more skill biased (i.e.,  $A_h/A_l$  is higher) than in the initial BGP.*
- (ii) *If  $\lambda > \hat{\lambda}$ , then the offshoring shock induces a two-stage transition such that for some  $T$  and  $\tilde{T}$  ( $0 < T < \tilde{T} < \infty$ ), we have: (stage 1)  $\dot{\kappa}_t > 0$ ,  $\dot{A}_{l,t} = \dot{A}_{h,t} = 0$  for all  $t \in [0, T]$ ; (stage 2, UBTC)  $\dot{\kappa}_t = 0$ ,  $\dot{A}_{h,t} = 0$ , and  $\dot{A}_{l,t} > 0$  for all  $t \in [T, \tilde{T}]$ . The economy attains the new BGP at  $t = \tilde{T}$ . In the new BGP, the technology is less skill biased (i.e.,  $A_h/A_l$  is lower) than in the initial BGP.*

Upon impact, the increase in  $\lambda$  triggers a wave of offshoring investments. The initial stage of the transition which goes on over the interval  $[0, T]$  (stage 1) features a continuous increase in  $\kappa$  (hence,  $V_l^o - V_l = f$ ) but no innovation. The intuition for why innovation is temporarily paused is that offshoring opportunities cause a discrete increase in the interest rate. At this higher interest rate, innovation becomes unprofitable, i.e.,  $V_h < \mu$  and  $V_l < \mu$ . Over time, the offshoring rate increases, restoring ultimately the profitability of innovation in either high- or low-skill industries.

Which type of innovation is restored first depends on the initial level of  $\lambda$ . If  $\lambda$  was initially low, the shock triggers SBTC.<sup>24</sup> More formally, for low  $\lambda$ 's, the second stage of the transition is characterized by the conditions  $V_l^o - V_l = f$ ,  $V_h = \mu$  and  $V_l < \mu$ . Thus, there is both offshoring and high-skill innovation, but no low-skill innovation. Over time, the price adjustment reduces the gap between  $\pi_h$  and  $\pi_l$ , and restores low-skill innovation incentives and the economy eventually attains the new BGP. In contrast, if  $\lambda$  was initially high, the shock triggers UBTC in the second stage of the transition ( $V_l^o - V_l = f$ ,  $V_l = \mu$  and  $V_h < \mu$ ). Note

<sup>24</sup>The proposition discusses the effect of small changes in  $\lambda$ . With larger changes in  $\lambda$ , greater care is necessary; starting from  $\lambda < \hat{\lambda}$ , a large increase in  $\lambda$  could take the economy above  $\hat{\lambda}$  and have ambiguous effects.

that in this case  $\kappa$  reaches the new BGP level already at the end of the first stage of the transition. During stage 2, offshoring continues but the offshoring rate,  $\kappa$ , remains constant.

#### FIGURE 5 HERE

The changes in offshoring and technology affect wages in the West and the East. Figure 5 shows the transitional dynamics of wages in two cases corresponding to a low (Panel a) and a high (Panel b) initial  $\lambda$ , respectively.<sup>25</sup> In particular, it shows how the wages of the different types of workers (from top to bottom, high- and low-skill in the West, and low-skill workers in the East) evolve over time during the transition relative to the counterfactual wage dynamics under no shock (dashed lines). In both cases, the high-skill wage is higher than in the no-shock baseline throughout the whole transition, and the low-skill wage in the West exhibits U-shaped dynamics. In Panel a (SBTC), the low-skill wage remains below the no-shock counterfactual throughout the whole transition. In Panel b (UBTC), it surpasses the no-shock counterfactual at the end of the transition. In both cases, the offshoring shock causes large wage gains in the East.

In all cases, the new BGP has a higher growth rate, implying that all workers will earn higher wages in a sufficiently far future. Consequently, low-skill workers in the West face a trade-off between short-run wage losses and long-run wage gains. The welfare consequences of the increase in offshoring and the resolution of this trade-off are discussed in the next section.

#### D. Quantitative Analysis

In this subsection, we undertake a quantitative analysis to shed further light on two aspects of our theory. Our analysis shows that the SBTC induced by (the reductions in the cost of) offshoring contributes to the increase in inequality in the West, but is silent on whether this indirect effect could be of the same order of magnitude as the direct impact of offshoring. This is the first objective of our quantitative analysis. Secondly, our theoretical implications are ambiguous on welfare effects—even low-skill workers in the West could be in principle made better off by lower costs of offshoring. Our aim is not to provide a detailed calibration, but to gauge the implications of our theory for these two questions under reasonable parameter values.<sup>26</sup>

We set the parameters so as to enable the model to match some salient facts of the global economy in the year 2000. We identify the West with the United

<sup>25</sup>The parameter choices for these figures are discussed in the next section.

<sup>26</sup>See Arkolakis et al. (2013), Di Giovanni et al. (2014) and Tintelnot (2014) for detailed quantitative analyses of models of international trade with multinational production, but without the endogenous technology channel studied here (and without the analytical characterization permitted by our framework).

States and the East with China. We normalize the size of the unskilled labor in the West to  $L_w = 1$ . The labor force of China is set to  $L_e = 4.7$ , to match the relative size of the Chinese urban labor force.<sup>27</sup> We set  $H_w = 1.2$  so as to match the relative skill endowment (as measured by the share of workers with college degree or more) in the United States. We choose the short-run elasticity of substitution between high- and low-skill workers as  $\epsilon = 1.6$ , consistent with the estimates by Ciccone and Peri (2005).<sup>28</sup> Since most studies find the elasticity of substitution between traded goods to be greater than 3, we set  $\sigma = 3.33$ .<sup>29</sup> We set  $\rho = 0.04$  which, when combined with a 2% growth rate, implies a rate of return on equity of 6%. The innovation cost,  $\mu$ , is chosen to yield a pre-shock annual BGP growth rate of 2%. Motivated by the recent slowdown in the world growth rates, we also consider an alternative low-growth scenario where  $\mu$  is consistent with a 1% annual growth rate, close to the average of the US economy between 1995 and 2010. We set  $\tau = 1.5$ . This choice is somewhat arbitrary, but the results are not very sensitive to this parameter.<sup>30</sup> Finally, the parameters  $\lambda$  and  $Z$  are set to match, respectively, the PPP-adjusted wage gap between Chinese and low-skill US workers,  $w_{l,e}/w_{l,w} = 0.16$ , and the skill premium in the US,  $\omega_w = 1.9$ , in 2000.<sup>31</sup> Given that in the model Chinese workers can only be employed in offshored firms,  $\kappa$  should be interpreted not simply as the extent of offshoring, but as a broad measure of technologies imported from the world to the Chinese economy.

We first explore the effects of integration between the United States and China on the BGP skill premium. We find that, if factor endowments were kept constant, the US skill premium in autarky ( $\lambda = 0$ ) would be 1.26, instead of 1.9. Thus, integration with China accounts for an increase in the skill premium by approximately 50%. Of this effect, around 60% is explained by the static forces discussed in Section 2.2, while the remaining 40% is driven by SBTC. This result thus suggests that the indirect effects of (the reductions in the cost of) offshoring on wage inequality in the West working through technology are roughly of the same order of magnitude as its direct effects.

Next, we assume the economy to be in a BGP in 2000 and study the effects of an “offshoring shock,” captured by a fall in the fixed cost of offshoring,  $f$ . We set

<sup>27</sup>The average size of the unskilled US labor force is 61 million. This is derived from the total number of non-agricultural workers in the US, which is 135 million (source: Current Population Survey). Of these, 61 million are classified as unskilled (“high school graduates or less”) and 74 million are classified as skilled (“some college or more”) workers. The average number of urban workers in China over the last decade is 286 million (source: China Statistical Yearbook).

<sup>28</sup>Keeping  $L_w/L_e$  constant,  $\epsilon = 1.6$  implies a long-run elasticity—meaning an elasticity allowing for the endogenous technology adjustment—of 2.5.

<sup>29</sup>We view this as a conservative benchmark as higher values of  $\sigma$  tend to increase the magnitude of the welfare effects. In fact, in the working paper version, we show that with  $\sigma = 5$ , the main qualitative implications are similar but welfare effects are somewhat larger.

<sup>30</sup>For instance, in the working paper version, we show that setting  $\tau = 1$  yields similar results.

<sup>31</sup>The wage gap is calculated using the ratio between the average US wage and the average urban wage in China (from the China Statistical Yearbook). This is adjusted to yield the ratio between the average Chinese urban wage and the US low-skill wage (own calculation). The PPP is from the Penn World Table. The US skill premium is from Acemoglu and Autor (2011).

the size of the offshoring shock so as to generate changes in the volume of trade broadly consistent with the data. During the period 2000-08, imports plus export as a share of GDP in the US economy increased by 19% (Penn World Tables 7.1) and trade in intermediates increased by around 25% (Feenstra and Jensen 2012). We therefore choose the fall in  $f$  to obtain a 20% increase in the volume of US trade. Since the volume of trade depends on income differences, the shock maps directly into the US-China wage gap: as a consequence, the wages of Chinese workers relative to US unskilled workers grow from the initial level of 0.16 to 0.21, which is almost half of the catch-up observed in the data. The resulting transitional dynamics feature a pure offshoring stage followed by SBTC.

In Table 1, we report the effect of the offshoring shock on the growth rate ( $g$ ), on the US skill premium ( $\omega_w$ ) and on welfare of all workers, expressed as the equivalent change in their level of consumption in the old BGP ( $\Delta c_{h,w}^*$ ,  $\Delta c_{l,w}^*$  and  $\Delta c_{l,e}^*$ ).<sup>32</sup> In column (1), we consider the benchmark 2% growth scenario, in which offshoring increases the BGP growth rate of the world economy from 2% to 2.2%. The shock has strong distributional effects: the US skill premium increases from 1.9 to 2.06. For comparison, this is about 80% of the variation in the demand for skill observed during the period 2000-08.<sup>33</sup> In welfare terms, Chinese workers make large gains (26%), followed by the skilled workers in the US (8%). Unskilled workers in the West also gain, but only a modest 1.3%.

In column (2), we consider the same experiment in the alternative low-growth scenario where offshoring increases the BGP growth rate of the world economy from 1% to 1.17%. In this case, all welfare gains are smaller and US unskilled workers lose out. The fact that the gains are smaller when the growth in the world economy is lower is a reflection of the long-run complementarity between innovation and offshoring: offshoring increases the BGP growth rate, and in addition, a high innovation potential speeds up the transition so that the long-run benefits from offshoring materialize faster.

The welfare results are partly driven by the effect of offshoring on growth. Whether there is such a growth effect from offshoring is secondary to our theoretical focus. Our choice of the baseline model was motivated by theoretical transparency. An alternative model that incorporates directed technical change into a semi-endogenous growth model (without growth effects) along the lines of Jones (1995) is outlined in Acemoglu (2002) and could be easily used as our basic model without any significant implications for our main results—except that the impact of offshoring on growth would be absent. Motivated by this, in column (3), we neutralize the growth effect by changing simultaneously the cost of off-

<sup>32</sup>Welfare effects also depend on the initial asset distribution, which is difficult to observe. We therefore assume that the initial share of world assets held by each group of workers is proportional to the present value of their wages in the initial BGP.

<sup>33</sup>In our simulations, we keep  $H_w/L_w$  constant to avoid mixing different shocks. Over the period 2000-08, however, the US skill premium increased from 1.9 to 2 and the average educational attainment has grown from  $H_w/L_w = 1.2$  to 1.37. For comparison, our estimates of elasticities imply that, with  $H_w/L_w$  remaining constant at 1.2, the skill premium would have reached  $\omega_w = 2.1$ .

shoring ( $f$ ) and of innovation ( $\mu$ ) so as to keep the BGP growth rate constant before and after the shock. This experiment allows us to isolate the redistributive effects of technology, which is our main focus, while remaining agnostic on the determinants of long-run growth. It also captures the essence of models of semi-endogenous growth, as well as of models suggesting that offshoring may increase innovation costs due to, for example, coordination problems (as in Naghavi and Ottaviano 2009). The welfare gains of all agents are now smaller, and turn into significant losses for the unskilled workers in the United States.

Finally, we study the effect of an offshoring shock starting from a smaller initial wage gap between China and the US, a likely relevant scenario in the future. In column (4), we change the initial offshoring cost so as to obtain a higher relative wage in China, equal to 50% of the US unskilled wage. This corresponds to a scenario where  $\lambda > \hat{\lambda}$ , so that the offshoring cost induces UBTC. The size of the offshoring shock is set to be such that it generates an increase in the Chinese wage of 5 percentage points relative to the corresponding US level, as in the previous experiments. As in column (3), we neutralize growth effects by changing the cost of innovation so as to keep  $g = 2\%$ . The fact that the offshoring shock induces now UBTC has important distributional implications. In this case, the unskilled workers in the United States make sizeable gains, even larger than those accruing to the skilled workers.

	(1)	(2)	(3)	(4)
$w_{l,e}/w_{l,w} \mid_{t=0}$	0.16	0.16	0.16	0.50
$g_0$	2%	1%	2%	2%
$g_{\tilde{T}}$	2.2%	1.17%	2%	2%
$\omega_w \mid_{t=\tilde{T}}$	2.06	2.06	2.06	2.33
$\Delta c_{h,w}^*$	8.04%	6.04%	3.32%	2.99%
$\Delta c_{l,w}^*$	1.32%	-0.28%	-3.07%	3.99%
$\Delta c_{l,e}^*$	26.38%	23.33%	20.81%	12.33%

TABLE 1—WELFARE EFFECTS, 2000-08

In conclusion, our quantitative analysis suggests that the welfare effects of offshoring are highly asymmetric and that low-skill workers in the West may lose out. Our analysis also implies that fostering innovation can be important to counteract the negative distributional effects, since losses are less likely in the high-growth scenario. Finally, consistent with our theoretical results, the quantitative analysis shows that the adverse distributional effects of offshoring may decrease, or even subside, as the technological gap between China and the West declines. This is due to the main new result of our framework—the change in the direction of technical change at different initial levels of offshoring.

### III. Extensions

We now extend our benchmark model in two directions. First, we allow for offshoring in high-skill intermediates/tasks. This extension shows how lower costs of offshoring can lead to greater wage inequality both in the West and the East. Second, we allow Eastern firms to transfer technology from the West also by imitating Western technologies. This extension leads to a dynamic equilibrium path in which the East can grow rapidly as it switches from the less efficient imitation strategy to offshoring, and somewhat reminiscent of the Chinese experience over the last two decades, this process can take place without wage growth.

#### A. High-Skill Offshoring

We now assume that the East is endowed with  $H_e$  units of skilled labor, but maintain that the West is skill abundant:  $H_w/L_w > H_e/L_e$ . For simplicity and to save space, we restrict the analysis to the BGP and focus on the effects of  $\lambda$  only.<sup>34</sup> We also assume that the unit cost of offshoring ( $\tau$ ) is the same in both sectors.

For given technology  $(A_h, A_l)$  and offshoring rates  $(\kappa_h, \kappa_l)$ , the skill premia in the West and East are:

$$\begin{aligned}\omega_w &= \left(\frac{ZA_h}{A_l}\right)^{1-1/\epsilon} \left(\frac{\hat{H}}{\hat{L}}\right)^{-1/\epsilon} \left(\frac{\hat{H}}{\hat{L}}\right)^{1-\alpha} \left(\frac{L_w}{H_w} \frac{1-\kappa_h}{1-\kappa_l}\right)^{1-\alpha}, \\ \omega_e &= \left(\frac{ZA_h}{A_l}\right)^{1-1/\epsilon} \left(\frac{\hat{H}}{\hat{L}}\right)^{-1/\epsilon} \left(\frac{\hat{H}}{\hat{L}}\right)^{1-\alpha} \left(\frac{L_e}{H_e} \frac{\kappa_h}{\kappa_l}\right)^{1-\alpha},\end{aligned}$$

where  $\hat{H} \equiv \left(\kappa_h^{1-\alpha} (H_e/\tau)^\alpha + (1-\kappa_h)^{1-\alpha} H_w^\alpha\right)^{1/\alpha}$ . The comparative statics of changes in  $(\kappa_h, \kappa_l)$  follow directly from the baseline case.

More interesting results can be derived when offshoring is endogenous. We start from the simpler case in which the fixed costs of offshoring are the same in the two sectors. Then, the equilibrium offshoring rate is pinned down by the conditions  $\lambda\pi_{l,e} = \pi_{l,w}$  and  $\lambda\pi_{h,e} = \pi_{h,w}$ . Substituting in the expressions of profits yields:

$$\begin{aligned}\kappa_l &= \left(1 + \tau\lambda^{-1/\alpha} L_w/L_e\right)^{-1} \\ \kappa_h &= \left(1 + \tau\lambda^{-1/\alpha} H_w/H_e\right)^{-1}.\end{aligned}$$

Since the East is skill-scarce, it is easy to see that the relative extent of offshoring,  $\frac{\kappa_l}{\kappa_h}$ ,

<sup>34</sup>The model with high-skill offshoring has an additional state variable, which makes a complete characterization of transitional dynamics more cumbersome.



declines monotonically from  $\frac{H_w/H_e}{L_w/L_e}$  to  $\frac{1+\tau H_w/H_e}{1+\tau L_w/L_e}$  as  $\lambda$  increases. Interestingly, offshoring is endogenously more prevalent in the low-skill sector. This is intuitive: the relative abundance of unskilled labor in the East induces Western firms to offshore production relatively more in the unskilled sector. As  $\lambda$  increases, however, offshoring increases relatively more in the lagging skilled sector. This pattern accords well with the available evidence.

Next, the indifference conditions between domestic and offshore production in both sectors imply that the international wage gap in both sectors is given by:

$$\frac{w_{l,w}}{w_{l,e}} = \frac{w_{h,w}}{w_{h,e}} = \tau \lambda^{\frac{\alpha-1}{\alpha}}.$$

An important implication is that the skill premium is the same in both countries: offshoring generates conditional factor price equalization, even if the two countries are fully specialized and have different technological capabilities. This result is driven by the assumption that the cost of offshoring is the same in both sectors, which in turn implies that the value of offshoring, which is proportional to the East-West wage difference, must also be equalized. This is accomplished by a higher offshoring rate in the unskilled sector, so as to increase the relative demand and hence the wage for unskilled workers in the East.

The common BGP skill premium in the West and the East,  $\omega = \omega_w = \omega_e$ , is now:

$$\begin{aligned} \omega &= Z^{\epsilon-1} \left( \frac{\hat{L}}{\hat{H}} \right)^{1-\epsilon+\epsilon\alpha} \left( \frac{1-\kappa_h}{1-\kappa_l} \frac{L_w}{H_w} \right)^{1-\epsilon\alpha} \\ &= Z^{\epsilon-1} \left( \frac{\hat{L}}{\hat{H}} \right)^{1-\epsilon+\epsilon\alpha} \left( \frac{\tau L_w + \lambda^{1/\alpha} L_e}{\tau H_w + \lambda^{1/\alpha} H_e} \right)^{1-\epsilon\alpha}. \end{aligned}$$

The fact that  $H_w/L_w > H_e/L_e$  implies that an increase in  $\lambda$  raises both terms in parenthesis. Intuitively, offshoring has a larger impact in the unskilled sector because the East has a relatively larger endowment of unskilled workers. It follows that the comparative statics in response to changes in  $\lambda$  are similar to the baseline case. In particular, depending on the elasticities  $\epsilon$  and  $\alpha$ , the relationship between  $\lambda$  and  $\omega_w$  is still likely to be non-monotonic. Figure 6 plots the relationship between  $\omega$  and offshoring opportunities,  $\lambda$ , using the calibration of the previous section. The graph shows both the previously studied case in which  $H_e = 0$  (solid line) and the case in which 10% of workers in the East are skilled (dashed line). Clearly, adding high-skill offshoring does not change the qualitative relationship between the skill premium in the West and offshoring: the shape of the two lines is similar, with the only difference being that, with a larger skill-endowment in the East, the effect of offshoring on the skill premium is smaller (the red line is below the black line). Interestingly, for sufficiently low levels of offshoring, a fall

in offshoring costs raises skill premia both in the origin and destination countries. These predictions are broadly consistent with the evidence reported in Ge and Yang (2014), who find that the college premium in China increased from around 1.3 in 1992 to more than 1.6 in 2007, and in Sheng and Yang (2012), who find that processing exports and FDI can account for 75% of the increase in the Chinese college wage premium between 2000 and 2006.

FIGURE 6 HERE

The results are easily generalized to the case in which offshoring costs are different in the two sectors. In this case, the BGP skill premium would also vary across locations. In particular, if the cost of offshoring was larger for high-skill jobs ( $\lambda_h < \lambda_l$ ), then there would be less  $H$ -offshoring, resulting in lower demand for skilled workers in the East and a lower skill premium compared to the West:  $\omega_e = \omega_w (\lambda_h/\lambda_l)^{(1-\alpha)/\alpha}$ . The generalized model can explain why, despite its scarcity of skilled labor, the skill premium in China is lower than in the United States and why it has increased in both countries.

#### *B. Imitation, Trade and Offshoring*

So far, the only mode of technology transfer from West to East has been offshoring. In this section, we add the possibility for local firms in the East to imitate Western technologies. Imitation is modelled as an inferior form of technology transfer: the labor productivity for producing an intermediate is lower with imitation than under offshoring, for example because tacit knowledge of Western firms prevents perfect imitation. However, imitation entails no payment of monopoly rents to the innovating firms in the West. We show that in this environment, two regimes emerge: as long as offshoring costs are sufficiently high, technology transfer occurs only through imitation. However, when offshoring costs become sufficiently low, offshoring starts prevailing and less productive local imitating firms gradually disappear.

More specifically, we assume that Eastern firms can copy existing intermediates at a small cost and become local monopolists. However, technology transfer via imitation is imperfect: imitated intermediates are produced with a worse technology, with labor productivity equal to  $\varphi < 1$ . There is free trade in final goods,  $Y_h$  and  $Y_l$ . Intermediates can also be traded, but foreign trade entails a small flow cost to be paid independently of the quantity exported. As a result, trade in final goods will equalize prices in both countries and there will be no trade in individual intermediates.<sup>35</sup> To simplify, we focus on the case where  $\tau = 1$  and

<sup>35</sup>The assumption of (small) trade costs, which is quite realistic, avoids complications arising from two producers being active in the same market. More formally, the equilibrium can be described by the following game: there are two producers (Eastern and Western monopolist) of the same variety. The

$\varphi < \alpha$ . Then, the monopoly price charged by a firm that offshores production to the East is lower than the marginal cost of a local imitator. In this case, offshoring, when it happens, drives imitated intermediates out of business.

Let us now start with the benchmark without offshoring (but with imitation). Eastern firms imitate all intermediates and there is trade in  $Y_h$  and  $Y_l$  only. The relative (world) price of these goods is:

$$(21) \quad \frac{P_h}{P_l} = \left( \frac{A_h}{A_l} \frac{ZH_w}{L_w + \varphi L_e} \right)^{-1/\epsilon}$$

The skill bias of the technology is determined by the incentive to innovate in the West. The relative profitability of skill-complementary technologies is:

$$\frac{V_h}{V_l} = \frac{\pi_{h,w}}{\pi_{l,w}} = \frac{P_h ZH_w}{P_l L_w}.$$

Along the BGP, all types of innovations must be equally profitable, thus  $V_h = V_l$ . This condition combined with (21) yields BGP relative technologies as:

$$(22) \quad \frac{A_h}{A_l} = \left( \frac{ZH_w}{L_w} \right)^\epsilon \frac{L_w + \varphi L_e}{ZH_w}.$$

Intuitively, in a world with no offshoring, imitation affects the direction of technical progress in the West through the price effect—there is no market size effect because of lack of IPR. Better imitations (higher  $\varphi$ ) lead to greater production of unskilled goods in the East and so to a higher relative price of skilled goods. This induces SBTC.

Now consider a reduction in offshoring costs that makes offshoring profitable. In this case, there is a switch from a BGP with only imitation to one with pure offshoring. To determine when this happens, note that offshoring will be profitable, starting from a BGP without offshoring, when

$$(23) \quad \frac{\pi_{l,e}^o - \pi_{l,w}}{r} \geq f,$$

where  $\pi_{l,w}$  is the equilibrium profit in the West under no offshoring;  $r = \pi_{l,w}/\mu$  is the corresponding BGP interest rate; and  $\pi_{l,e}^o$  denotes the profit of an individual Western firm that deviates from a no-offshoring equilibrium and offshores pro-

Eastern producer has a technological disadvantage, but this is perfectly offset in equilibrium by a lower wage. The infinitesimal trade cost keeps the two markets segmented. The Eastern producer knows that, if it paid the trade cost, it would enter a stage game in the Western market in which Bertrand competition would drive profits to zero. The same argument keeps the Western producer from entering the Eastern market. Therefore, in equilibrium, each producer serves the local market. See Acemoglu, Gancia and Zilibotti (2012) for details.

duction to the Eastern market. Such a deviating firm can pay Eastern workers a wage that is only a fraction  $\varphi$  of the Western wage, and still access the state-of-the-art technology. In view of this, condition (23) ensures that starting from the BGP with only imitation, offshoring will be profitable. Substituting for profits, (23) can be rewritten as  $\varphi \leq \lambda^{\frac{1-\alpha}{\alpha}}$ . When  $\varphi \leq \lambda^{\frac{1-\alpha}{\alpha}}$ , Western firms will find it profitable to offshore to the East.

Let us now characterize the BGP that emerges after offshoring. The first important observation is that although in a BGP with offshoring only a fraction  $\kappa$  of the intermediates are offshored, there will be no imitation in the remaining intermediates. The reason is that all Eastern producers now face higher wages: though without offshoring the technological disadvantage of Eastern producers was offset by the lower wages in the East—enabling local producers with imitated technology to be active in all markets—this is no longer the case with offshoring, and thus low-productivity imitators in the East can no longer survive when Eastern wages are pushed up due to offshoring. As a result, offshoring induces specialization: in the new BGP, the East will export the intermediates produced in the offshored sectors to the West, and the West will produce and export to the East the remaining intermediates. Inferior (imitated) technologies will be abandoned.

The transitional dynamics are interesting. Consider an increase in  $\lambda$ , which initiates the transition from a BGP with only imitation to a BGP with offshoring. We will first have a period of offshoring in which, as already discussed, there will be no innovation. During this phase, offshoring will also push out low-productivity imitating firms in the East. During this process, however, wages in the East do not increase until all low-productivity (imitator) firms have exited the market. Thus, equilibrium dynamics take the form of rapid growth accompanied by the reallocation of workers from low-productivity firms to high-productivity firms with no wage growth. The intuition for this result is related to Song et al. (2011). The transitional dynamics enter their second phase when all low-productivity imitators have exited and wages in the East start growing again. The rest of the transition to the BGP is identical to the benchmark model. Whether the second stage features SBTC or UBTC again depends on whether (16) is higher or lower than (22) evaluated at  $\varphi > \lambda^{\frac{1-\alpha}{\alpha}}$ .

#### IV. Conclusions

Offshoring of jobs to low-wage countries and SBTC are among the most prominent and fiercely debated trends of the US labor market. This paper has shown how these two phenomena are likely to be interlinked—because of the impact of offshoring on the direction of technical change.

Our theoretical analysis provides several new insights on these interlinkages. Most importantly, we show that a decline in the cost of offshoring has in general ambiguous effects on the level of wages, the skill premium and the direction of technical change. Nevertheless, our analysis clearly identifies the contrasting

effects and their relative magnitudes. In the most plausible scenario, starting from a high cost of offshoring, a decline in offshoring costs triggers a transition characterized initially by falling real wages for unskilled workers in the West and followed by SBTC. These implications highlight why, in contrast to the conventional wisdom, offshoring could have a major impact on wage inequality even when—*particularly when*—the extent of trade and offshoring is limited. Interestingly, despite leaving out several important determinants of wage inequality in the United States, our model accords fairly well with the available evidence on US labor market trends of the 1980s and early 1990s.

The implications of offshoring are very different, however, once its cost is sufficiently low: in this case, because past offshoring has already contributed to a narrowing of the wage gap between the West and the East, further offshoring will induce unskilled-biased technical change and a lower skill premium. This suggests that the future potential distributional effects of offshoring could be quite different than its past impact. We also characterize the dynamics of wages and technology after a fall in the cost of offshoring and the implication for welfare.

The tractable nature of our framework enables several extensions, two of which we have discussed. First, we study offshoring of both low- and high-skilled intermediates and find that, in contrast to the standard Stolper-Samuelson theorem, globalization can lead to higher skill premia even in skill-scarce countries. Second, we investigate the transition of the East from low-productivity imitation to higher-productivity offshoring, which leads to a pattern of transition reminiscent of the Chinese process of economic growth over the last three decades. Our model could be further extended in several other directions, including by incorporating a more realistic production structure with different types of labor and capital, innovation emanating from the East, and the possibility that offshored technologies be copied by local producers in the East.

## APPENDIX

## A1. Technical Analysis in Section 2

The representative household sets a consumption plan to maximize utility, subject to an intertemporal budget constraint and a no-Ponzi game condition. The consumption plan satisfies a standard Euler equation,  $\dot{C}_t/C_t = r_t - \rho$ , and a corresponding transversality condition,  $\lim_{t \rightarrow \infty} \left[ \exp \left( - \int_0^t r_s ds \right) W_t \right] = 0$ , where  $r_t$  is the interest rate, and  $W_t$  is the wealth of consumers which comes from their ownership of firms in the economy.<sup>36</sup>

Profit maximization yields the following inverse demand functions for  $Y_l$  and  $Y_h$ :

$$(A1) \quad P_l = (Y/Y_l)^{1/\epsilon} \quad \text{and} \quad P_h = (Y/Y_h)^{1/\epsilon},$$

where  $P_l$  and  $P_h$  are the world prices of  $Y_l$  and  $Y_h$ , respectively. Similarly, we obtain the inverse demand functions for varieties of intermediates:

$$(A2) \quad p_{l,i} = P_l E_l^\alpha Y_l^{1-\alpha} x_{l,i}^{\alpha-1} \quad \text{and} \quad p_{h,i} = P_h E_h^\alpha Y_h^{1-\alpha} x_{h,i}^{\alpha-1},$$

where  $p_{l,i}$  ( $p_{h,i}$ ) is the price of the intermediate variety  $i$ , with  $i \in [0, A_l]$  ( $i \in [0, A_h]$ ).

Since the demand for each intermediate has a constant elasticity equal to  $\sigma \equiv 1/(1-\alpha)$ , profit maximizing firms charge prices equal to a markup  $1/\alpha$  over the respective marginal cost:  $p_{h,i} = (w_h/Z)/\alpha$  and  $p_{l,i} = w_{l,w}/\alpha$  for intermediates produced in the West, and  $p_{l,i} = \tau w_{l,e}/\alpha$  for intermediates produced in the East. Profits are therefore a fraction  $(1-\alpha)$  of the value of sales and, using (2), (3), (4) and (A2), they can be written as:

$$(A3) \quad \begin{aligned} \pi_h &= (1-\alpha) P_h H, & \pi_{l,w} &= (1-\alpha) P_l \hat{L}^{1-\alpha} \left( \frac{L_w}{1-\kappa} \right)^\alpha, \\ \pi_{l,e} &= (1-\alpha) P_l \hat{L}^{1-\alpha} \left( \frac{L_e}{\tau \kappa} \right)^\alpha. \end{aligned}$$

<sup>36</sup>In particular, we have

$$W_t = \left( \int_0^{A_{h,t}} V_{j,t} di + \int_0^{A_{l,t}} V_{j,t} dj \right),$$

where  $V_{j,t} = \int_t^\infty \exp \left[ - \int_t^s r_{s'} ds' \right] \pi_{j,s} ds$ ,  $\pi_{j,s}$  is the profits of the firm operating intermediate  $j$  in sector  $s \in \{l, h\}$  as given by (A2) below, and  $A_{s,t}$  is the range of active intermediates in sector  $s$ .

Substituting the expression of  $x_h$  given in (4) into (2), and using (3) yields:

$$(A4) \quad Y_h = A_h Z H.$$

To find the expression of the skill premium given in the text, (8), plug-in the expressions in (A2) into  $\omega_w = Z(p_{h,w}/p_{l,w})$ . Then, standard algebra using equations (3), (4), (6), (A1), and (A4) yields equation (8). Similarly, the expression of the low-skill wage, (9), is found by substituting in the expression for  $p_{l,w}$  in (A2) into  $w_{l,w} = \alpha p_{l,w}$ . Then, equation (9) can be obtained from equations (3) and (4).

#### A2. Proof of Proposition 1

The effect of  $\kappa$  on  $\omega_w$  follows from (8) as discussed in the text. To establish the effect of  $\kappa$  on  $w_{l,w}$ , use  $P_l = (Y/Y_l)^{1/\epsilon}$  and (6) into (9) to get:

$$w_{l,w} = \alpha \left( \frac{Y}{A_l} \right)^{1/\epsilon} A_l \hat{L}^{1-\alpha-1/\epsilon} \left( \frac{1-\kappa}{L_w} \right)^{1-\alpha}.$$

Differentiate this to obtain:

$$\frac{\partial \ln w_{l,w}}{\partial \kappa} = \eta \frac{\partial \hat{L}}{\partial \kappa} - \frac{1-\alpha}{1-\kappa},$$

where  $\eta \equiv \frac{1-\alpha+(1-\alpha-1/\epsilon)(A_h Z H_w / A_l \hat{L})^{\frac{\epsilon-1}{\epsilon}}}{\hat{L} + \hat{L}(A_h Z H_w / A_l \hat{L})^{\frac{\epsilon-1}{\epsilon}}}$ . As  $\kappa \rightarrow \bar{\kappa}$ ,  $\frac{\partial \hat{L}}{\partial \kappa} \rightarrow 0$ . Hence,  $w_{l,w}$  de-

creases unambiguously for large values of  $\kappa$ . Conversely, as  $\kappa \rightarrow 0$ ,  $\frac{\partial \hat{L}}{\partial \kappa} \rightarrow \infty$ . Hence, the sign of the effect depends on the sign of  $\eta$ . Note that  $\eta$  is positive if  $\sigma < \epsilon$  (i.e.,  $1-\alpha > 1/\epsilon$ ). However, if  $\sigma > \epsilon$  (i.e.,  $1-\alpha < 1/\epsilon$ ), then  $\eta$  is negative provided that condition (10) is satisfied. Since  $\lim_{\kappa \rightarrow 0} \hat{L} = L_w$  and using (8) and  $\sigma \equiv 1/(1-\alpha)$ , this condition can be rewritten as  $\omega_w H_w / L_w > \epsilon/(\sigma - \epsilon)$ .

The real wages of other workers are  $w_{h,w} = \alpha Z p_{h,w}$  and  $w_{l,e} = \alpha p_{l,e}/\tau$ . Using (3), (4), (6), (A1), (A2) and (A4) yields:

$$\begin{aligned} w_{h,w} &= \alpha \left( \frac{Y}{A_h Z H_w} \right)^{\frac{1}{\epsilon}} Z A_h, \text{ and} \\ w_{l,e} &= \frac{\alpha}{\tau} \left( \frac{Y}{A_l} \right)^{\frac{1}{\epsilon}} A_l \hat{L}^{1-\alpha-1/\epsilon} \left( \frac{\kappa}{L_e} \right)^{1-\alpha}. \end{aligned}$$

Both  $w_{h,w}$  and  $w_{l,e}$  are increasing in  $\kappa$  since  $\frac{\partial Y}{\partial \kappa} > 0$ , and because  $\hat{L}^{1-\alpha-1/\epsilon} \kappa^{1-\alpha}$

is increasing in  $\kappa$ .

To sign the effect of  $\tau$  on  $w_{l,w}$ , note that  $\frac{\partial \ln w_{l,w}}{\partial \tau} = \eta \frac{\partial \hat{L}}{\partial \tau}$ . Since  $\frac{\partial \hat{L}}{\partial \tau} < 0$ , the sign of the effect depends on the sign of  $\eta$ , hence, on condition (10), as discussed above.

### A3. Proof of Proposition 2

Substituting  $\lambda \equiv (f/\mu + 1)^{-1}$  into (14) yields  $\pi_{l,w} = \lambda \pi_{l,e}$ . Using (A3) and solving for  $\kappa$  yields (15). To find the BGP value of  $A_h/A_l$ , note that (14) requires that  $\pi_h = \pi_{l,w}$ . Using (6), (A1), (A4) and (A3), and solving for  $A_h/A_l$ , yields (16). Finally, substituting (A3) into  $r = \pi_h/\mu$  and rearranging terms using (1), (6), (15), (A1), and (A4) yields:

$$(A5) \quad r = \frac{1-\alpha}{\mu} \left\{ \left[ \hat{L}^{1-\alpha} \left( L_w + \lambda^{1/\alpha} L_e \tau^{-1} \right)^\alpha \right]^{\epsilon-1} + (ZH_w)^{\epsilon-1} \right\}^{\frac{1}{\epsilon-1}}.$$

Standard arguments imply that consumption,  $Y$ ,  $Y_h$ ,  $Y_l$ ,  $A_h$  and  $A_l$  all grow at the common rate  $g = r - \rho$ , which is strictly positive provided that  $\rho\sigma\mu < \min\{L_w, ZH_w\}$ . Since in BGP,  $V_l = V_h = \mu$  and  $V_l^o = \mu + f$  (from (13)), the transversality condition becomes

$$\lim_{t \rightarrow \infty} \left[ \exp \left( - \int_0^t r_s ds \right) (A_{h,t} \mu + A_{l,t} (\mu + \kappa f)) \right] = 0.$$

As  $A_l$  and  $A_h$  grow at the rate  $g$ , and  $r = \rho + g > g$ , this condition is satisfied in the unique BGP.

### A4. Proof of Proposition 4

The effect of  $\lambda$  on the skill premium along the BGP can be analyzed by differentiating (20) with respect to  $\lambda$ :

$$(A6) \quad \frac{\partial \ln \omega_w}{\partial \lambda} = \left[ (1 - \epsilon + \epsilon\alpha) \frac{\partial \ln \hat{L}}{\partial \kappa} + \frac{1 - \epsilon\alpha}{1 - \kappa} \right] \frac{\partial \kappa}{\partial \lambda}.$$

Note that, as  $\lambda \rightarrow 0$ , then,  $\kappa \rightarrow 0$  and  $\frac{\partial \ln \hat{L}}{\partial \kappa} \rightarrow \infty$ . Thus,  $\frac{\partial \ln \omega_w}{\partial \lambda} > 0$  for sufficiently low values of  $\lambda$ . As  $\lambda \rightarrow 1$ , instead,  $\kappa \rightarrow \bar{\kappa}$  and  $\frac{\partial \ln \hat{L}}{\partial \kappa} \rightarrow 0$ . Thus, for sufficiently high values of  $\lambda$ , equation (A6) shows that  $\frac{\partial \ln \omega_w}{\partial \lambda}$  has the same sign as  $(1 - \epsilon\alpha)$ .



To study the effect of  $\tau^{-1}$ , substitute (7) and (15) into (20), and obtain:

$$\frac{\partial \ln \omega_w}{\partial \tau^{-1}} = \frac{L_e \lambda^{1/\alpha}}{\alpha} \left[ \frac{1 - \epsilon + \epsilon \alpha}{\lambda L_w + \lambda^{1/\alpha} L_e / \tau} - \frac{(\epsilon - 1)(2\alpha - 1)}{L_w + \lambda^{1/\alpha} L_e / \tau} \right].$$

At  $\lambda = 0$ , the sign of this derivative depends on the sign of  $(1 - \epsilon + \epsilon \alpha)$ . At  $\lambda = 1$ ,  $\frac{\partial \ln \omega_w}{\partial \tau^{-1}} = \frac{-L_e(\epsilon-2)}{L_w + L_e/\tau}$ . Finally, straightforward algebra shows that  $\frac{L_w + \lambda^{1/\alpha} L_e / \tau}{\lambda L_w + \lambda^{1/\alpha} L_e / \tau}$  is decreasing in  $\lambda$ . Thus,  $\frac{\partial \ln \omega_w}{\partial \tau^{-1}}$  can change sign at most once.

#### A5. Proof of Proposition 5

PRELIMINARY RESULTS. —

LEMMA 1: *Suppose there are no unanticipated shocks for all  $t \geq s$ , and at  $t = s$ ,  $V_z = \mu$ , with  $z = \{h, l\}$ . Then  $V_z = \mu$  for all  $t > s$ . Similarly, if at  $t = s$  we have  $V_l^o - V_l = f$ , then  $V_l^o - V_l = f$  for all  $t > s$ .*

PROOF:

If  $V_z = \mu$  at  $t = s$ , but  $V_z < \mu$  later, then it would imply an anticipated capital loss, violating (11) or (12).

LEMMA 2: *The conditions  $V_l = V_h = \mu$  and  $V_l^o - V_l = f$  are both necessary and sufficient for the economy to be in a BGP.*

PROOF:

$V_h = V_l = \mu$  and  $V_l^o - V_l = f$  are simultaneously satisfied only for unique values of  $\kappa$ , which in turn defines  $A_h/A_l$  uniquely.

Define  $r_{off} \equiv (\tilde{\lambda} \pi_{l,e} - \pi_{l,w})/f$ ,  $r_h \equiv \pi_{h,w}/\mu$ , and  $r_l \equiv \pi_{l,w}/\mu$ . Here  $r_{off}$  is the equilibrium interest rate when there is positive offshoring (it follows from  $V_l^o - V_l = f$ );  $r_h$  is the equilibrium interest rate when there is positive technical change in the skilled sector (it follows from  $V_h = \mu$ );  $r_l$  is the equilibrium interest rate when there is positive technical change in the unskilled sector (it follows from  $V_l = \mu$ ).

GENERAL CHARACTERIZATION. — Given no uncertainty, no arbitrage implies that  $r(A_{h,t}, A_{l,t}, \kappa_t) = \max\{r_{off}, r_h, r_l\}$ . In a BGP,  $r_{off} = r_h = r_l$ . The world equilibrium path can then be described by the following system of differential equations:

$$(A7) \quad \frac{\dot{C}_t}{C_t} = r(A_{h,t}, A_{l,t}, \kappa_t) - \rho$$

$$(A8) \quad \mu \dot{A}_{h,t} + (\mu + f \kappa_t) \dot{A}_{l,t} + f A_{l,t} \dot{\kappa}_t = Y(A_{h,t}, A_{l,t}, \kappa_t) - C_t$$

with boundary conditions given by  $\kappa_0$ ,  $A_{h,0}$  and  $A_{l,0}$  at  $t = 0$  and a transversality condition. Here  $C$  is the consumption of the world representative agent, and  $Y$  is the world GDP, defined as

$$Y(A_{h,t}, A_{l,t}, \kappa_t) = \left( 1 + \left( \frac{A_{l,t} \hat{L}(\kappa_t)}{A_{h,t} Z H_w} \right)^{\frac{\epsilon-1}{\epsilon}} \right)^{\frac{\epsilon}{\epsilon-1}} A_{h,t} Z H_w,$$

where, recall,  $\hat{L}(\kappa_t) = \left[ \kappa_t^{1-\alpha} (L_e/\tau)^\alpha + (1-\kappa_t)^{1-\alpha} L_w^\alpha \right]^{1/\alpha}$ .

Consider now the impact effect of a (positive) offshoring shock. Since  $\pi_{l,e}$ ,  $\pi_{l,w}$  and  $\pi_{h,w}$  (and, hence,  $r_h$  and  $r_l$ ) are not affected by changes in  $f$  while  $r_{off}$  increases if  $f$  falls, then, upon the shock, the following condition must hold:

$$(A9) \quad r(A_{h,t}, A_{l,t}, \kappa_t) = r_{off} > r_h = r_l.$$

Lemma 1 guarantees that offshoring never stops for  $t > 0$ . Thus, for all  $t > 0$ ,  $r(A_{h,t}, A_{l,t}, \kappa_t) = r_{off}$ , implying that

$$r(A_{h,t}, A_{l,t}, \kappa_t) = \left( \frac{Y(A_{h,t}, A_{l,t}, \kappa_t)}{A_{l,0} \hat{L}(\kappa_t)} \right)^{\frac{1}{\epsilon}} \frac{(1-\alpha)}{f} \left( \hat{L}(\kappa_t) \right)^{1-\alpha} \left( \left( \frac{L_e}{\tau \kappa_t} \right)^\alpha - \left( \frac{L_w}{1-\kappa_t} \right)^\alpha \right).$$

THE FIRST STAGE OF THE TRANSITION: PURE OFFSHORING. — In the first stage of the transition, (A9) implies that  $V_l^o - V_l = f$ ,  $V_h < \mu$  and  $V_l < \mu$ . Then, the dynamic system, (A7)-(A8), simplifies to:

$$(A10) \quad \frac{\dot{C}_t}{C_t} = r(A_{h,0}, A_{l,0}, \kappa_t) - \rho$$

$$(A11) \quad f A_{l,0} \dot{\kappa}_t = Y(A_{h,0}, A_{l,0}, \kappa_t) - C_t$$

where  $\kappa_0$  is pinned down by the pre-shock BGP condition,  $\kappa_0 = \left( 1 + \lambda_0^{-1/\alpha} \tau L_w / L_e \right)^{-1}$ . The assumption that the economy starts from a BGP further implies that

$$A_{h,0} = (Z H_w)^{\epsilon-1} \left( \kappa_0^{1-\alpha} (L_e/\tau)^\alpha + (1-\kappa_0)^{1-\alpha} L_w^\alpha \right)^{\frac{1-\epsilon+\epsilon\alpha}{\alpha}} \left( L_w + \lambda_0^{1/\alpha} L_e/\tau \right)^{-\epsilon\alpha} A_{l,0}.$$

Thus, for given  $A_{l,0}$ ,  $A_{h,0}$  is uniquely pinned down by the BGP requirement.

Next, we prove that the pure offshoring stage of the transition ( $r_{off} > r_h$  and  $r_{off} > r_l$ ) must end in finite time, restoring positive innovation. Suppose, to obtain a contradiction, that this is not the case, so there is no innovation

thereafter. First, we can rule out that (for any  $\varepsilon > 0$ )  $r(A_{h,0}, A_{l,0}, \kappa_t) > \rho + \varepsilon$  for all  $t$ . If this were true,  $C_t$  would grow unbounded, which contradicts the fact that with no innovation  $Y(A_{h,0}, A_{l,0}, \kappa_t)$  is bounded (recall, in particular, that  $\kappa_t \leq \bar{\kappa}$ , so continuous growth without innovation is not possible). This implies that, without innovation, the dynamic system must converge to a steady state with zero growth and with  $r(A_{h,0}, A_{l,0}, \kappa) = \rho$ . But  $r_{h,t} > \rho$  throughout, since  $r_{h,0} > \rho$  and  $r_h$  is increasing in  $\kappa$ , which is itself increasing along the transition path. This implies that at some point  $r(A_{h,0}, A_{l,0}, \kappa) = r_{h,t}$ , triggering skill-biased innovations, and yielding a contradiction.

Next, we look at whether the stage of pure offshoring is followed by SBTC or UBTC. Note that, during the pure offshoring stage of transition,

$$\frac{r_{l,t}}{r_{h,t}} = \left( \frac{A_{h,0}}{A_{l,0}} \right)^{\frac{1}{\epsilon}} (ZH_w)^{\frac{1-\epsilon}{\epsilon}} \left( \hat{L}(\kappa_t) \right)^{1-\alpha-\frac{1}{\epsilon}} \left( \frac{L_w}{1-\kappa_t} \right)^{\alpha}.$$

In general, it is ambiguous whether  $r_l/r_h$  is increasing or decreasing in  $\kappa$ . However, it is easy to establish that there exists  $\hat{\kappa} \in (0, \bar{\kappa})$  such that (i)  $r_l/r_h$  is decreasing in  $\kappa$  for  $\kappa < \hat{\kappa}$ ; (ii)  $r_l/r_h$  is increasing in  $\kappa$  for  $\kappa \geq \hat{\kappa}$ . This can be seen from the derivative:

$$\frac{\partial \ln(r_l/r_h)}{\partial \kappa} = \left( 1 - \alpha - \frac{1}{\epsilon} \right) \frac{\partial \ln \hat{L}}{\partial \kappa} + \frac{\alpha}{1 - \kappa}.$$

By assumption,  $1 - \alpha - 1/\epsilon < 0$ . Then, the result follows from the fact that  $\partial \ln \hat{L} / \partial \kappa$  decreases monotonically from  $\infty$  at  $\kappa \rightarrow 0$  to 0 at  $\kappa \rightarrow \bar{\kappa}$ . In case (i), the pure offshoring stage is followed by a stage of the transition in which the equilibrium features offshoring and SBTC ( $V_l^o - V_l = f$ ,  $V_h = \mu$  and  $V_l < \mu$ ). In case (ii), the stage of pure offshoring is followed by a stage in which the equilibrium features offshoring and UBTC ( $V_l^o - V_l = f$ ,  $V_l = \mu$  and  $V_h < \mu$ ). The convergence to the new BGP must be studied separately for each of the two cases.

#### SECOND STAGE OF THE TRANSITION: OFFSHORING+FACTOR BIASED TECHNICAL CHANGE.

CASE 1: SBTC ( $\kappa < \hat{\kappa}$ ). — We start by pinning down the offshoring rate,  $\kappa^{SBTC}$ , that triggers a switch from pure offshoring to SBTC+offshoring ( $\dot{\kappa}_t > 0$ ,  $\dot{A}_{h,t} > 0$  and  $\dot{A}_{l,t} = 0$ ).  $\kappa^{SBTC}$  is implicitly determined by the condition  $r_{off} = r_h$ , which can be rewritten as

$$\frac{A_{h,0}}{A_{l,0}} = \frac{\hat{L}(\kappa^{SBTC})^{1-\epsilon+\epsilon\alpha}}{(ZH_w)^{1-\epsilon}} \left[ \left( \frac{L_e}{\tau \kappa^{SBTC}} \right)^{\alpha} - \left( \frac{L_w}{1 - \kappa^{SBTC}} \right)^{\alpha} \right]^{-\epsilon} \left( \frac{f}{\mu} \right)^{\epsilon}.$$

As proven above,  $\kappa_t$  will attain  $\kappa^{SBTC}$  in finite time. Let  $T > 0$  denote the time in which SBTC+offshoring starts ( $\kappa_T = \kappa^{SBTC}$ ). Note that  $T$  can be determined by numerical integration. For all  $t \geq T$ , the condition  $r_{off} = r_h$  must hold, and this yields

$$(A12) \quad A_{h,t} = A_h(\kappa_t) = \frac{\hat{L}(\kappa_t)^{1-\epsilon+\epsilon\alpha}}{(ZH_w)^{1-\epsilon}} \left[ \left( \frac{L_e}{\tau\kappa_t} \right)^\alpha - \left( \frac{L_w}{1-\kappa_t} \right)^\alpha \right]^{-\epsilon} \left( \frac{f}{\mu} \right)^\epsilon A_{l,0}.$$

The equilibrium dynamics can therefore be expressed as:

$$(A13) \quad \frac{\dot{C}_t}{C_t} = r(A_h(\kappa_t), A_{l,0}, \kappa_t) - \rho,$$

$$(A14) \quad \left( \mu \frac{\partial A_h(\kappa_t)}{\partial \kappa_t} + f A_{l,0} \right) \dot{\kappa}_t = Y(A_h(\kappa_t), A_{l,0}, \kappa_t) - C_t,$$

for  $t \geq T$ , with the initial condition  $\kappa_T = \kappa^{SBTC}$ . Note that equation (A12) allows us to reduce the number of state variables in the dynamic system to one.

Next, we show that low-skill innovation is restored in finite time. Suppose, to obtain a contradiction, that the SBTC+offshoring stage never ends. Since  $\kappa \leq \bar{\kappa}$ , (A12) implies that  $A_h(\kappa_t)$  and  $Y(A_h(\kappa_t), A_{l,0}, \kappa_t)$  are bounded. Thus, the same argument used to prove that the stage of pure offshoring must end in finite time can be used to establish that (i) if the transition featuring SBTC+offshoring continued forever, then  $r(A_h(\kappa_t), A_{l,0}, \kappa_t)$  would fall to  $\rho$ , and the economy would attain a steady state with zero growth; (ii) in converging to a steady state with zero growth,  $r$  would decline sufficiently to trigger UBTC, yielding a contradiction.

In summary, the argument above establishes that there exists  $\tilde{T} < \infty$  such that, for  $t \geq \tilde{T}$ ,  $V_l^o - V_l = f$ ,  $V_h = V_l = \mu$ , and the economy attains the new BGP. Using the terminal condition  $\kappa_{\tilde{T}} = (1 + \lambda^{-1/\alpha} \tau L_w / L_e)^{-1}$  (where  $\lambda$  is the after-shock index) together with (A13)–(A14) yields the time for switch  $\tilde{T}$ .

CASE 2: UBTC ( $\kappa \geq \hat{\kappa}$ ). — In this case, the conditions  $V_l^o - V_l = f$  and  $V_l = \mu$  must hold simultaneously, i.e.,  $r_{off} = r_l$ . But because this is the condition that determines the BGP level of offshoring, in this stage  $\kappa$  must be at its (after-shock) BGP level (15). Since (15) only depends on exogenous parameters, in this stage there is offshoring, but  $\kappa$  remains constant over time. The system of equations characterizing equilibrium simplifies then to

$$(A15) \quad \frac{\dot{C}_t}{C_t} = r(A_{h,0}, A_{l,t}, \kappa) - \rho,$$

$$(A16) \quad (\mu + f\kappa) \dot{A}_{l,t} = Y(A_{h,0}, A_{l,t}, \kappa) - C_t.$$

This is a system of autonomous differential equations in  $C_t$  and  $A_{l,t}$ , with the initial condition  $A_{l,T} = A_{l,0}$ . It is straightforward to show, as in case 1, that this transition cannot go forever, since the technology features decreasing returns to  $A_{l,t}$  (holding constant  $\kappa$  and  $A_h$ ), and thus  $r$  would fall to  $\rho$ . However, this is impossible, and thus innovation in the skilled sector is restored in finite time. In fact, skill-biased innovation is restored as soon as  $r_l = r_h$ . This occurs at  $t = \tilde{T}$  such that

$$A_{l,\tilde{T}} = A_{h,0} \left( \left( \hat{L}(\kappa) \right)^{1-\alpha-1/\epsilon} \left( \frac{L_w}{1-\kappa} \right)^\alpha (ZH_w)^{1/\epsilon-1} \right)^\epsilon.$$

Thereafter the BGP dynamics apply.

The characterization of the equilibrium consumption trajectories is presented in the next subsection.

CHARACTERIZATION OF THE EQUILIBRIUM CONSUMPTION TRAJECTORIES AND WELFARE. — To complete the analysis of the full equilibrium dynamics, in section we characterize the equilibrium consumption trajectory. In particular, we solve for  $C_0$  for arbitrary initial conditions that may be inconsistent with a BGP. We denote by  $\tilde{T}$  the time in which the economy attains the BGP. The BGP expression of consumption yields

$$\begin{aligned} \frac{C}{A_l} &= \left( \frac{Y(A_h, A_l, \kappa)}{A_l} - \mu g \left( 1 + \frac{A_h}{A_l} \right) \right), \\ \frac{C}{A_h} &= \left( \frac{Y(A_h, A_l, \kappa)}{A_h} - \mu g \left( 1 + \left( \frac{A_h}{A_l} \right)^{-1} \right) \right), \end{aligned}$$

where  $g = \left\{ \left[ \hat{L}^{1-\alpha} (L_w + \lambda^{1/\alpha} L_e / \tau)^\alpha \right]^{\epsilon-1} + (ZH_w)^{\epsilon-1} \right\}^{\frac{1}{\epsilon-1}} (1-\alpha) / \mu - \rho$  and, recall,  $A_h/A_l$ ,  $Y/A_h$  and  $Y/A_l$  are constant in a BGP. Then, in case 1 ( $\kappa \leq \hat{\kappa}$ ),

$$C_{\tilde{T}} = \left( \frac{Y(A_h, A_l, \kappa)}{A_l} - \mu g \left( 1 + \left( \frac{A_h}{A_l} \right) \right) \right) \times A_{l,0},$$

whereas, in case 2 ( $\kappa > \hat{\kappa}$ ),

$$C_{\tilde{T}} = \left( \frac{Y(A_h, A_l, \kappa)}{A_h} - \mu g \left( 1 + \left( \frac{A_h}{A_l} \right)^{-1} \right) \right) \times A_{h,0}.$$

In addition, for all  $t \leq \tilde{T}$ , the time paths of  $\kappa$ ,  $A_{h,t}$  and  $A_{l,t}$  are fully determined. Note, in particular, that in case 1  $A_{l,\tilde{T}} = A_{l,0}$ , and in case 2  $A_{h,\tilde{T}} = A_{h,0}$ , which yields the expressions for all other variables at time  $\tilde{T}$  (in terms of the BGP expressions of  $A_h/A_l$ ,  $Y/A_h$  and  $Y/A_l$ ).

Given the terminal conditions  $\{C_{\tilde{T}}, A_{h,\tilde{T}}, A_{l,\tilde{T}}, \kappa_{\tilde{T}}\}$ , the system of differential equation (A13)–(A14) in case 1 and (A15)–(A16) in case 2 can be integrated backwards to yield a solution for  $\{C_T, A_{h,T}, A_{l,T}, \kappa_T\}$ , where, recall,  $T$  is the the endpoint of the first stage of the transition (pure offshoring). Likewise, one can use  $\{C_T, A_{h,T}, A_{l,T}, \kappa_T\}$  as the terminal condition of the first stage of the transition to integrate backwards the system of differential equations (A10)–(A11), and find a solution for the initial consumption,  $C_0$ , given the other initial conditions,  $A_{h,0}, A_{l,0}, \kappa_0$ .

These consumption trajectories refer to the world representative agent. To compute the discounted utility of different types of agents, use the Euler equation to write agent  $i$ 's discounted utility evaluated at time  $t = 0$  as:

$$(A17) \quad U_{i,0} = \int_0^\infty e^{-\rho t} \ln C_{i,t} dt = \frac{\ln C_{i,0}}{\rho} + \int_0^\infty e^{-\rho t} \left( \int_0^t r_s ds - \rho t \right) dt.$$

The initial consumption,  $C_{i,0}$ , can be found by combining the Euler equation and the lifetime budget constraint:

$$(A18) \quad C_{i,0} = \rho \left( \int_0^\infty w_{i,t} \exp \left( - \int_0^t r_s ds \right) dt + a_{i,0} \right),$$

where  $w_{i,t}$  is agent  $i$ 's wage and  $a_{i,0}$  is the value of his asset holdings at  $t = 0$ . The only assets in positive net supply in the economy are claims to the profit flow of existing firms. The present value of firm  $j$  evaluated at time  $t = 0$  is given by  $V_{j,0} = \int_0^\infty \exp \left( - \int_0^t r_s ds \right) \pi_{j,t} dt$ . Along a BGP,  $V_{j,0} = \mu$ . However, during the first stage of the transition we have  $V_{j,0} < \mu$ , and so the offshoring shock causes a capital loss to asset owners (by increasing the world interest rate).

#### A6. Effect of Offshoring Opportunities When $\sigma < \epsilon$

In this section, we establish the comparative statics of a change in  $\kappa$  on wages and skill premia when offshoring is exogenous (Proposition 6), and the comparative statics of a change in  $\lambda$  on offshoring, the direction of technical change, the interest rate wages (Proposition 7) and on wages and skill premia (Proposition 8) when offshoring is endogenous. Proofs are omitted as they follow immediately from the proofs of Propositions 1, 3 and 4.

PROPOSITION 6: Suppose  $1 < \sigma < \epsilon$ . With exogenous technology and offshoring, an increase in offshoring, parameterized by an increase in  $\kappa$ :

- (i) increase the real wage of skilled workers in the West,  $w_{h,w}$  and the real wage of unskilled workers in the East,  $w_{l,e}$ ;
- (ii) the impact of  $\kappa$  on  $w_{l,w}$  and  $\omega_w$  are inverse U-shaped: they increase  $w_{l,w}$  and decrease  $\omega_w$  for low initial values of  $\kappa$ ; they decrease  $w_{l,w}$  and increase  $\omega_w$  for high initial values of  $\kappa$ .

PROPOSITION 7: Suppose  $1 < \sigma < \epsilon$  and  $\rho\sigma\mu < \min\{L_w, ZH_w\}$ . In the BGP, greater offshoring opportunities parameterized by an increase of  $\lambda$ :

- (i) increase the offshoring rate,  $\kappa$ ;
- (ii) induce UBTC, i.e., lower  $A_h/A_l$ ;
- (iii) increase the equilibrium interest rate,  $r$ , and the growth rate,  $g$ .

PROPOSITION 8: Suppose  $1 < \sigma < \epsilon$  and  $\rho\sigma\mu < \min\{L_w, ZH_w\}$ . In the BGP, greater offshoring opportunities parameterized by an increase of  $\lambda$ :

- (i) reduce the wage gap between unskilled workers in the East and in the West,  $w_{l,e}/w_{l,w}$ ;
- (ii) decrease the skill premium,  $\omega_w$ , if  $\frac{\sigma}{\sigma-1} < \epsilon$ ; induce a U-shaped reaction in the skill premium,  $\omega_w$ , if  $\frac{\sigma}{\sigma-1} > \epsilon$  [i.e., decrease  $\omega_w$  for low initial  $\lambda$ , and increase  $\omega_w$  for high initial  $\lambda$ ];

\*

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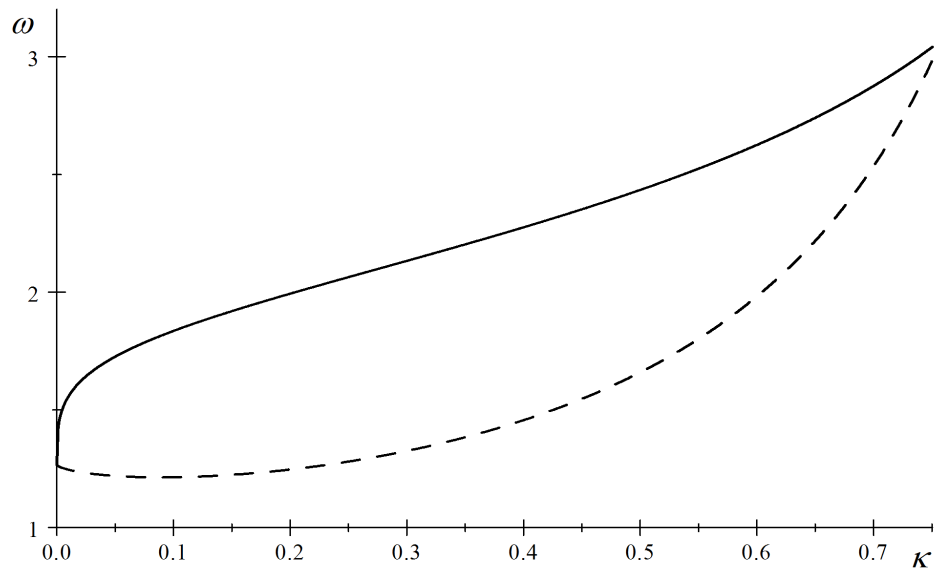


FIGURE B1. **Offshoring and the Skill Premium**

THE FIGURE SHOWS THE RELATIONSHIP BETWEEN OFFSHORING ( $\kappa$ ) AND THE SKILL PREMIUM IN THE WEST ( $\omega$ ) FOR THE CASES  $\epsilon = 1.6$ ,  $\sigma = 3.33$  (SOLID),  $\sigma = 1.11$  (DASHED). SEE SECTION 3.4 FOR THE REMAINING PARAMETERS.

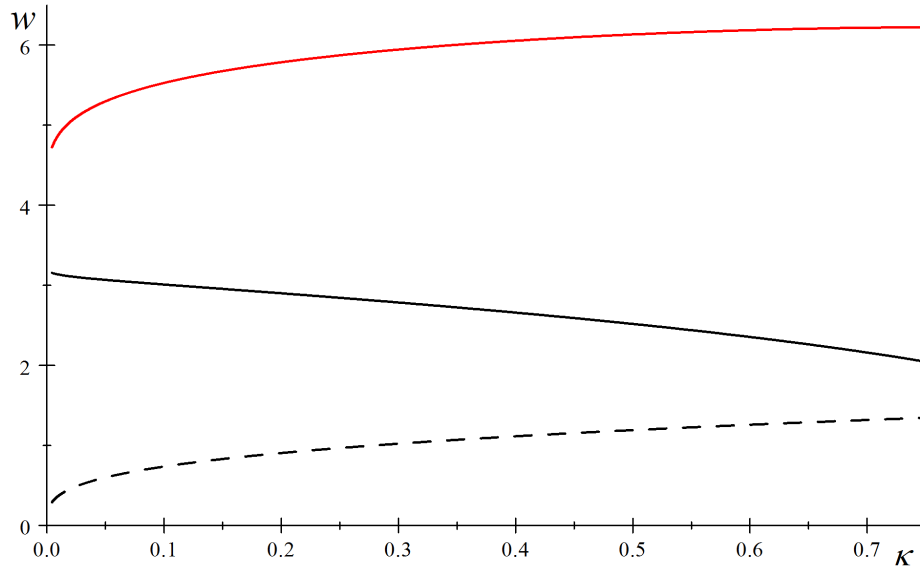


FIGURE B2. **Offshoring and Wages**

THE FIGURE SHOWS THE RELATIONSHIP BETWEEN OFFSHORING ( $\kappa$ ) AND WAGE LEVELS,  $w_{h,w}$  (RED),  $w_{l,w}$  (SOLID) AND  $w_{l,e}$  (DASHED), FOR THE CASE  $\epsilon = 1.6$  AND  $\sigma = 3.33$ . SEE SECTION 3.4 FOR THE REMAINING PARAMETERS.

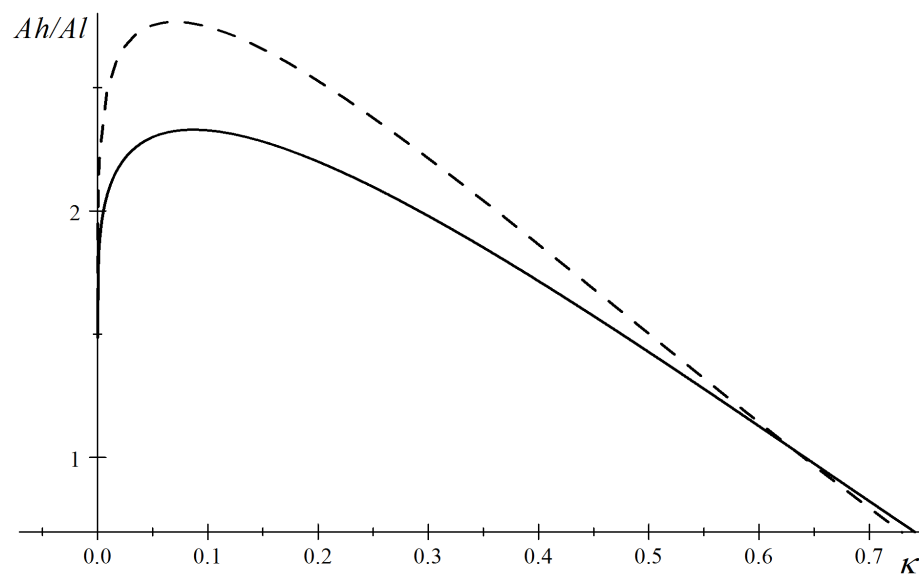


FIGURE B3. **Offshoring and Directed Technical Change**

THE FIGURE SHOWS THE RELATIONSHIP BETWEEN THE OFFSHORING RATE,  $\kappa = (1 + \lambda^{-1/\alpha} \tau L_w / L_e)^{-1}$ , AND  $A_h/A_l$  FOR THE CASE  $\epsilon = 1.6$ ,  $\sigma = 5$  (DASHED) AND  $\sigma = 3.33$  (SOLID). SEE SECTION 3.4 FOR THE REMAINING PARAMETERS.

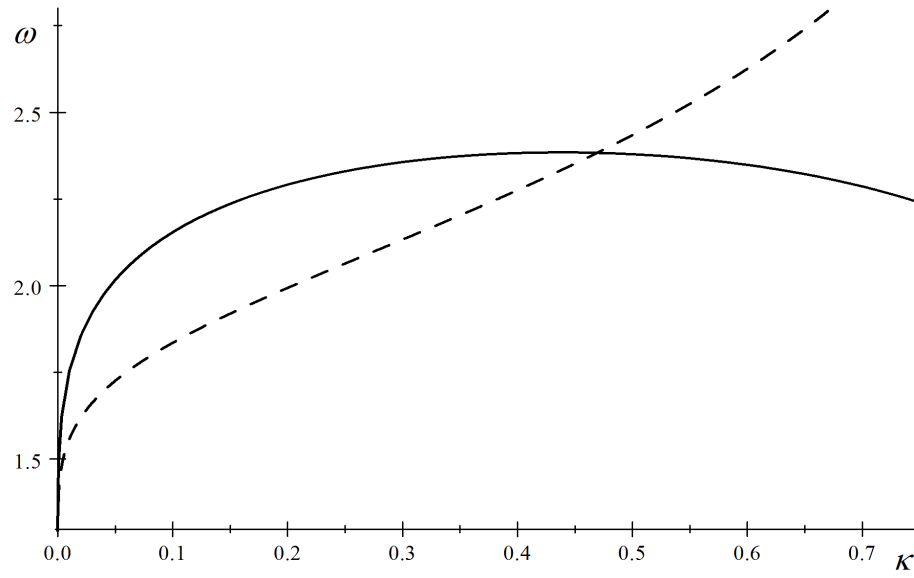


FIGURE B4. **Offshoring and the Skill Premium**

THE FIGURE SHOWS THE RELATIONSHIP BETWEEN THE SKILL PREMIUM IN THE WEST ( $\omega$ ) AND THE OFFSHORING RATE ( $\kappa = (1 + \lambda^{-1/\alpha} \tau L_w / L_e)^{-1}$ ) FOR ENDOGENOUS TECHNOLOGY (SOLID) AND EXOGENOUS TECHNOLOGY (DASHED). THE MAIN PARAMETERS ARE  $\epsilon = 1.6$ ,  $\sigma = 3.33$  AND THE OTHERS ARE DESCRIBED IN SECTION 3.4.

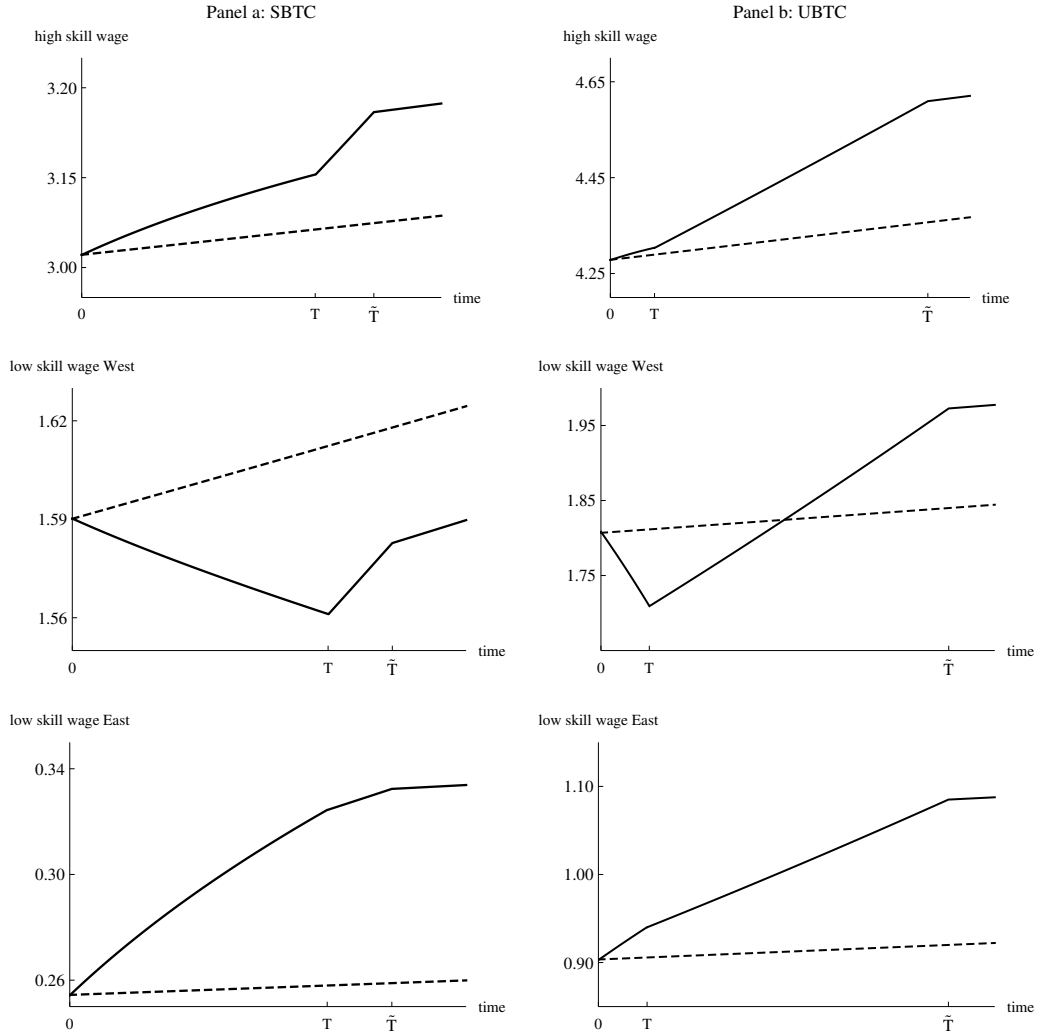


FIGURE B5. Transitional dynamics after an increase in  $\lambda$

THE FIGURE SHOWS THE RESPONSE OF HIGH-SKILL WAGES (TOP), LOW-SKILL WAGES IN THE WEST (MIDDLE) AND LOW-SKILL WAGES IN THE EAST (BOTTOM). PANEL A, ON THE LEFT, SHOWS THE RESPONSE OF WAGES TO A SHOCK THAT INDUCES SBTC (LOW INITIAL  $\kappa$ ). PANEL B, ON THE RIGHT, SHOWS THE RESPONSE OF WAGES TO A SHOCK THAT INDUCES UBTC (HIGH INITIAL  $\kappa$ ). DASHED LINES SHOW THE CORRESPONDING NO-SHOCK COUNTERFACTUAL.



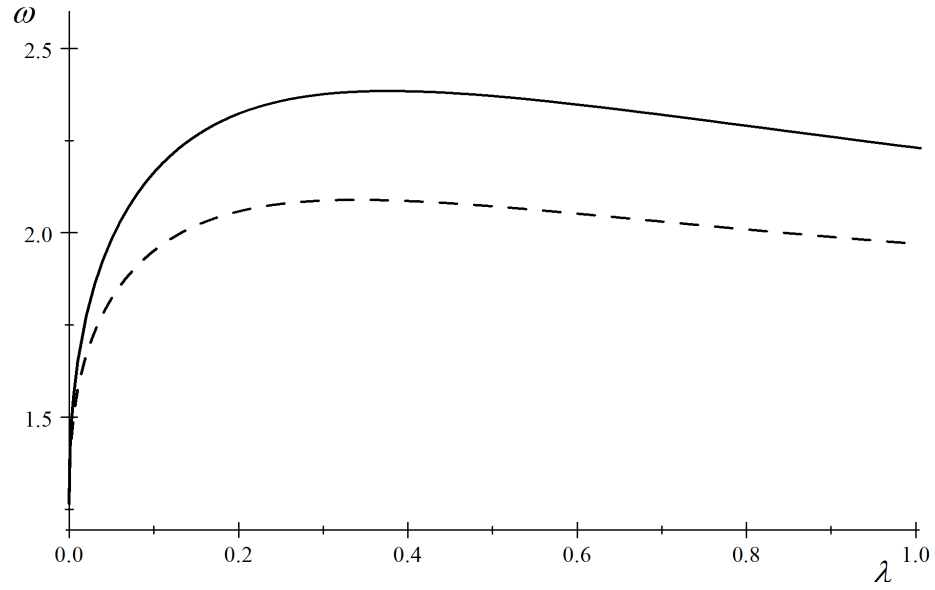


FIGURE B6. **High-Skill Offshoring and the Skill Premium**

THE FIGURE SHOWS THE RELATIONSHIP BETWEEN OFFSHORING ( $\lambda$ ) AND THE WORLD SKILL PREMIUM ( $\omega$ ) FOR THE CASES  $\epsilon = 1.6$ ,  $\sigma = 3.33$ ,  $H_e/L_e = 0.11$  (DASHED),  $H_e/L_e = 0$  (SOLID). SEE SECTION 3.4 FOR THE OTHER PARAMETERS.